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# RESEARCH MEMORANDUM

## USE OF FLAME-IMMERSED BLADES TO IMPROVE COMBUSTION LIMITS AND EFFICIENCY OF A 5-INCH DIAMETER CONNECTED-PIPE, RAM-JET COMBUSTOR

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RESEARCH MEMORANDUM

# USE OF FLAME-IMMERSED BLADES TO IMPROVE COMBUSTION LIMITS AND EFFICIENCY OF A 5-INCH DIAMETER, CONNECTED-PIPE, RAM-JET COMBUSTOR

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## SUMMARY

The effects of flame-immersed blades on combustion stability and efficiency were determined at various combustor-inlet conditions by using several geometrical blade arrangements, two fuels, two fuel-injection systems, and two blade temperatures. Flat blades, $3\frac{1}{2}$ by $\frac{13}{16}$ by $\frac{1}{8}$ inches, were immersed in the flame zone downstream of a conventional V-gutter baffle in a 5-inch-diameter, connected-pipe, ram-jet combustor.

Specific combustor configurations with flame-immersed blades showed marked improvement in stability and efficiency. The surface temperature of the immersed blades exhibited a second-order effect on the combustion stability and efficiency, thereby indicating that the role of the flame-immersed blades was primarily aerodynamic in character rather than thermal. Attempts at duplicating the benefits of flame-immersed blades by other means such as by variations in the gutter dimensions or by upstream-air vortex generation were unsuccessful.

The combustion efficiency of a burner configuration containing blades designed to increase mixing of the flame with fresh mixture downstream of the V-gutter flame holder was improved over that of a V-gutter alone. In addition, the combustion efficiency of this configuration was less sensitive to pressure than that of a V-gutter flame holder alone for the range of pressures investigated (0.45 to 1 atm).

## INTRODUCTION

In the current efforts to improve ram-jet combustor performance, major emphasis has been placed upon the design of components upstream of the flame such as flame holders, fuel-injection systems, and other parts of the induction system; and relatively little has been done in the flame region itself. The combustion reactants are placed together in the combustion chamber, which affords space for reaction. In the case of baffle-type flame holders no assistance other than the recirculation zone of the flame holder is provided for the combustion reaction. In the case of the can-type combustor, somewhat more control of the addition of air or mixture to the burning gases is achieved by means of the axially spaced holes, but no aerodynamic control exists within the combustion space itself. The main reason for this is that materials that can survive in the combustion atmosphere are not readily available. It was feared that the reaction would be seriously quenched if materials were externally cooled.

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Combustion efficiency and stability can be affected by surfaces placed in the flame zone which are frequently called "flame-immersed surfaces" (refs. 1 to 3). An increase in the limits of combustion in a ram-jet combustor resulting from the addition of carbon wedges in the flame zone is shown in reference 1. Oxidation of the carbon limited the investigation to intervals of short operational time.

Improvement in the combustion stability of a single gutter achieved by filling it with ceramic material is briefly reported in reference 2. The performance of a 4- by 8-inch rectangular ducted ram jet with up to 12 gutters in tandem is reported in reference 3, page 9. While Inconel gutters, which melted during testing, were used in obtaining most of the data in reference 3, a newly developed material, molybdenum coated with molybdenum disilicide, was found sufficiently resistant to melting and oxidation to be satisfactory as a flame-immersed material; it therefore was selected for use in this investigation.

This report indicates how the combustion stability and the efficiency of a V-gutter flame holder can be affected by immersing flat blades in the flame. Several geometrical arrangements, two fuels (gasoline and isopentane), two fuel-injection systems, and two blade temperatures were used with various combustor-inlet conditions. The temperature of the immersed blades was varied to isolate the aerodynamic effect of the immersed blade from the combined aerodynamic and thermal effects.

The investigation was conducted at the NACA Lewis laboratory during 1952.

## APPARATUS

The investigation reported herein was conducted in a 5-inch-diameter, connected-pipe, ram-jet combustor supplied with metered combustion air at a pressure of 55 pounds per square inch absolute. The combustion products were discharged to the laboratory exhaust system at a pressure of 2 pounds per square inch absolute (figs. 1 and 2). Sonic flow was maintained at the inlet air control unit shown in figure 1 to isolate any large pressure pulses occurring upstream in the supply system. The air mass flow was varied by moving a sleeve on the air control unit to vary the number of holes exposed to the air.

In order to obtain realistic ram-jet operating conditions, sonic flow was maintained with a two-dimensional variable-area exhaust nozzle (fig. 2). A metered water spray was introduced at the nozzle exit to quench the reaction and to permit determination of combustion efficiency by calorimetric methods.

Clear gasoline or isopentane metered by a rotameter was injected
2678 124 inches upstream of a V-gutter flame holder $1\frac{1}{2}$ inches wide by $1\frac{1}{2}$ inches high and was ignited by a momentary hydrogen-oxygen pilot in one end of the gutter.

The fuel injector consisted of two concentric tubes with two rows of 0.055-inch holes, drilled 180° apart, through both tubes. Fuel was supplied to the center tube and air to the annulus to atomize the spray. The fuel injector was mounted at the inlet of the diffuser perpendicular to the stream and oriented so that the fuel sprayed normal to the stream (fig. 2). For part of the investigation, a low fuel-injection pressure of about 10 pounds per square inch gage was used and, for the remainder of the investigation, a high pressure of 45 pounds per square inch gage was used.

Two types of blade were used (fig. 3); uncooled molybdenum blades protected from oxidation by a coating of molybdenum disilicide, and Inconel blades protected from melting by internal water cooling. Unless otherwise specified, the blades were uncooled. A maximum of 12 blades, $\frac{13}{16}$ by $3\frac{1}{2}$ by $\frac{1}{8}$ inches, were cantilever-mounted in the water-cooled combustor in various arrangements (fig. 4).

## PROCEDURE

The combustion efficiency was determined by operating the combustor at equilibrium at a given condition with the quench water rate adjusted so that the temperature of the exhaust gases was 600° F. Efficiency calculations were based on the ratio of the total enthalpy rise over the theoretical enthalpy rise possible if all the fuel were completely burned.

Efficiency calculations were made according to the following equation:

$$\eta = \frac{\sum(\Delta H_w + \Delta H_e + \Delta H_j)}{(H_c)(f/a)} \tag{1}$$

where

| | |
|---|---|
| $\eta$ | combustion efficiency |
| $\Delta H_w$ | enthalpy rise of water used to quench exhaust gases, Btu/lb original air |
| $\Delta H_e$ | enthalpy rise of exhaust gases, Btu/lb original air |
| $\Delta H_j$ | enthalpy rise of cooling jacket water, Btu/lb original air |
| $H_c$ | lower heating value of fuel, Btu/lb |
| $f/a$ | fuel-air ratio |



and where for mixtures richer than stoichiometric:

$$\Delta H_e = \Delta H_s + \left[(f/a)_e - (f/a)_s\right]\left[(L_v)_{T_i} + c_p(T_e - T_i)\right]$$

where

| | |
|---|---|
| $\Delta H_s$ | enthalpy rise of stoichiometric mixture, Btu/lb original air |
| $(f/a)_e$ | actual fuel-air ratio |
| $(f/a)_s$ | stoichiometric fuel-air ratio |
| $(L_v)$ | latent heat of vaporization, Btu/lb fuel |
| $c_p$ | mean heat capacity, Btu/($^{\circ}$F)/lb fuel |
| $T_e$ | temperature of exhaust gas, $^{\circ}$R |
| $T_i$ | inlet mixture temperature, $^{\circ}$R |

With this method of calculating combustion efficiency, it is not possible to attain values of 100 percent at fuel-air ratios in excess of stoichiometric.

Combustion limits were determined by gradually changing the fuel rate, or combustion pressure, from a condition of stable burning to a condition of no burning, a change which was definite and abrupt in all cases.

## RESULTS AND DISCUSSION

The basic data for combustion limits and efficiencies discussed in this section are presented in tables I and II.

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## Combustion Limits

Configurations I and II. - The combustion limits were determined for configurations I and II, illustrated in figures 4(a) and 4(b). Configuration I consists of a V-gutter flame holder alone and configuration II contains 12 molybdenum blades mounted in line with the V-gutter along the combustor axis and with the blade faces perpendicular to the axis. The data obtained at a combustor-inlet velocity of 220 feet per second and an inlet-mixture temperature of 200° F with isopentane and low-pressure fuel injection are shown in figure 5, in which the limits of combustion are plotted as functions of inlet pressure expressed in atmospheres and fuel concentration expressed as equivalence ratio, that is, the ratio of actual fuel concentration to the stoichiometric fuel concentration. The presence of the uncooled blades considerably extended the operable fuel concentration range both rich and lean and lowered the minimum operating pressure from 0.57 to 0.35 atmosphere.

Geometrical variations. - Inasmuch as the data in figure 5 show that the combustion limits were improved by the immersed molybdenum blades, the limits were also determined with the blades for the various geometrical configurations shown in figures 4(c) to 4(f) with isopentane and low-pressure fuel injection.

In configuration III (fig. 4(c)), two-thirds of the blades were removed from configuration II so as to leave blades in the first, fourth, seventh, and tenth positions. Figure 6(a) compares the limits of this configuration with the limits shown in figure 5 and shows that the limits lie approximately halfway between those of configurations I and II.

Configuration IV (fig. 4(d)) is similar to configuration II but has the first six blades removed. The data showing combustion limits are presented in figure 6(b) (analogous to fig. 6(a)), and they show that configuration IV was less effective than configuration II. It is thus indicated that the blades have more effect on the stability limit when placed nearer the gutter than the exhaust end of the combustor.

In configuration V (fig. 4(e)), all 12 blades were used as in configuration II except that all the blades were parallel to the combustor axis instead of perpendicular. The data showing combustion limits are shown in figure 6(c) and indicate that the parallel configuration was less than half as effective as configuration II. This suggests that the aerodynamic effect was important in stabilizing combustion when the blades were perpendicular to the combustor axis.

In configuration VI, the 12 blades again were used but were turned at a 45° angle to the combustor axis with alternate blades turned in opposite directions as illustrated in figure 4(f). The results shown in figure 6(d) show that the minimum pressure limit was as good as for configuration II, but the equivalence ratio limits were slightly reduced.

It might be concluded from the foregoing discussion that the combustion limit was improved as the number of blades used was increased up to the number tested (12) and that the combustion limit was a function of the wake patterns of the blades and was poorest when the blades were parallel to the combustor axis.

Fuel type. - Inasmuch as isopentane, used in the foregoing tests, has a much higher vapor pressure than conventional jet-engine fuels, the combustion limits of configuration VI were also determined with gasoline. 2678
The data are shown in figure 7 along with the data for isopentane. The minimum pressure limit was the same for both fuels, and the lean side of the curve was approximately similar for both fuels; but the gasoline appeared poorer than the isopentane on the rich side, probably because the low-pressure fuel injector was used and poor atomization penalized the gasoline mixture more severely than the more volatile isopentane. The data are interpreted to mean that the reported trends are probably not fuel sensitive for petroleum fuels.

High- and low-pressure fuel injection. - A study of the low-pressure fuel-injection system indicated that it did not deliver a completely homogeneous mixture to the combustor. A more nearly homogeneous mixture was obtained by increasing the atomizing air and fuel-injection pressure to about 45 pounds per square inch gage. The combustion limits of the V-gutter alone (configuration I) and of the in-line blades (configuration II), which are presented for the low-pressure injection system with isopentane in figure 5, were determined also for the high-pressure fuel-injection system with gasoline and are shown in figure 8. The data show that the high-pressure fuel injection improved the combustion limit of the V-gutter alone, but that the combustion limits of configuration II stayed virtually as shown in figure 5, indicating that the blades are more beneficial with a fuel system that does not give good spatial distribution than they are with a fuel system that does.

2-Inch gutter. - The isothermal pressure drop of configuration II was about 2.9 kinetic heads, which is 1 unit higher than that for the $1\frac{1}{2}$-inch V-gutter alone. Since increased stability sometimes accompanies increased pressure drop, an attempt was made to duplicate the combustion limits of the flame-immersed blades with a simple V-gutter flame holder by employing a wider V-gutter with a higher pressure drop. Consequently, the combustion limits of a 2-inch V-gutter with a pressure drop of 2.5 kinectic heads were compared with those of the $1\frac{1}{2}$-inch V-gutter used in all the other tests.

The data presented in figure 9 show that the combustion limits for the 2-inch V-gutter were poorer than for the $1\frac{1}{2}$-inch V-gutter. The decrease in stability was probably caused by the increased air velocity past the larger baffle. This is in agreement with the stability criterion, as reported in reference 4, which indicates that the optimum baffle-area blockage, with respect to combustion limits, occurs when the ratio of baffle area to gas velocity past the baffle is a maximum. According to this criterion, the optimum V-gutter width should be approximately $1\frac{1}{2}$ inches in a 5-inch-diameter duct.

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<u>Effect of surface temperature</u>. - The combustion limits of configuration II were determined with the water-cooled Inconel blades in order to separate the effect of hot surface from the aerodynamic effect, and these limits are compared in figure 10 with the data for configuration I and with the data for configuration II with uncooled blades. It can be seen that, while the limits of the cooled blades were less than those of the uncooled blades, the gain produced by the cooled blades was more than half that of the uncooled blades. Therefore, it appears that the blades in this position acted principally as aerodynamic baffles within the flame zone, and the surface temperature was of secondary importance in the stabilization mechanism. It should be noted that the closest blade to the V-gutter was $4\frac{1}{4}$ inches from it, and the surface temperature of any device closer to the V-gutter and immersed farther into the recirculation zone of the V-gutter may be of greater importance. The temperature of the uncooled molybdenum blades was as high as 2200° F, as indicated by optical pyrometer measurements.

The data show that noncritical materials can be used in a ram-jet design to improve performance because they can be cooled without severe combustion performance penalties.

The reproducibility of the combustion-limit data is indicated in figure 10 by check data for configuration I obtained on a different day.

## Efficiency

<u>Configurations I and II</u>. - Configurations I and II were used to determine if the mere presence of hot incandescent surfaces (up to 2200° F) might affect the combustion efficiency. This was done at three sets of operating conditions as indicated in figure 11. For the data in figure 11(b) the hydrogen-oxygen ignition flame was left on in order to obtain the data for the V-gutter alone inasmuch as the conditions are below the combustion limits. Isopentane with low-pressure fuel injection was used.

For all the conditions investigated, the combustion efficiency of configuration II was essentially the same as or slightly higher than that of configuration I.

Flame and mixture mixing. - Visual study of the flame downstream of the V-gutter suggested that a more rapid mixing of flame into the fresh mixture was needed to improve combustion efficiency. For this purpose 12 blades were installed in the combustion chamber in a manner intended to mechanically mix flame with fresh mixture, yet far enough downstream of the V-gutter so as not to upset the basic stability of the flame in the gutter wake. The arrangement, configuration VII, is shown in figure 4(g). The blades were arranged in three equally spaced rows; the rows were parallel to the stream with four blades to each row in equally spaced positions, but each blade occupied a different station in an alternating fashion from row to row. Each blade was inclined at an angle of attack of 45° to the stream, and all blades were turned in the same direction so as to indicate a right-hand threaded system.



The combustion efficiency of this configuration, shown as a function of equivalence ratio in figure 12, was 7 percentage points higher than corresponding data for a V-gutter alone at an equivalence ratio of 1 and 14 percentage points higher at an equivalence ratio of 0.8. The inlet conditions were pressure, 1.33 atmospheres; temperature, approximately 250° F; and velocity, 200 feet per second. Isopentane and low-pressure fuel injection were used for the data in figure 12.

Upstream vortex generation. - An attempt to match this increase in efficiency by imparting a vortex or swirl to the stream upstream of the baffle was made by installing two vortex generators 4 inches upstream of the baffle, as shown in figure 4(h), configuration VIII. These vortex generators were 1 inch wide and 3 inches long and inclined at a 10° angle of attack. The intended flow pattern was two contrarotating spirals in order to mix flame in the gutter-baffle wake with fresh mixture. The efficiency of configuration VIII is also shown in figure 12 and was less than 30 percent. The explanation is offered that the mixing occurred too soon, before the flame immediately behind the baffle was well established, and that mixing served more to quench the flame than to extend its propagation. This is supported by the fact that the combustion limits of configuration VIII, as indicated on the efficiency curves by the span of the curve, were much poorer than those of configurations I and II or VII.

Wider gutter. - Another attempt to duplicate the increase in efficiency achieved by configuration VII was made by increasing the baffle width from $1\frac{1}{2}$ to 2 inches since increased pressure drop can sometimes increase combustion efficiency. The resultant data with gasoline and the high-pressure fuel injector are shown in figure 13 and indicate that this change lowered the combustion efficiency approximately 5 percentage points.

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The conclusion from the data in figures 12 and 13 is that aiding or speeding up the mixing process between flame and fresh mixture with concurrent increase in over-all reaction rate is readily accomplishable downstream of the flame-holding baffle, but is difficult to achieve upstream of the flame region without interfering with the stability.

Cooled and uncooled blades. - The effect of the mixing blades of configuration VII was further investigated by determining the combustion efficiency with both cooled and uncooled blades. The data, which are presented in figure 14 along with the data for configuration I, were taken with gasoline and the high-pressure fuel injector at the following inlet conditions: pressure, 1 atmosphere; velocity, 200 feet per second; temperature, 200° F. The cooled blades produced approximately 80 percent as much increase in efficiency as the uncooled blades at an equivalence ratio of 1. These data seem to show that the aerodynamic mixing effect of the blades on combustion efficiency is great and the surface temperature effect, while appreciable, is notably less.

The significance of the foregoing discussion is that flame-immersed surfaces can be used in ram-jet combustor design to increase both combustion limits and efficiency, and also that noncritical materials can be assigned to this job since they can be cooled without severe performance penalties.

The improved combustion efficiency of configuration VII with the uncooled molybdenum blades compared with configuration I at a decreased inlet pressure of 0.67 atmosphere is shown in figure 15. The other inlet conditions were the same as those in figure 14.

Effect of pressure on efficiency with flame mixing. - The efficiency of configuration VII with uncooled molybdenum blades was investigated over a range of combustor-inlet pressures from 0.45 to 1 atmosphere with gasoline and the high-pressure fuel system. The resultant data are shown in figure 16.

The combustion efficiency data of reference 5 obtained for the same 5-inch-diameter combustor described herein with a V-gutter alone correlate with the inlet flow variables of static pressure $P$, temperature $T$, and velocity $V$ by the empirical parameter $P^{0.3}TV^{-0.8}$. The exponents of the variables were determined by taking the slope of the straight-line correlation when combustion efficiency is plotted against the variables individually on logarithmic coordinates. If the combustion efficiency data for configuration VII are cross-plotted from figure 16 at an equivalence ratio of 1, the exponent of the pressure coefficient in this empirical parameter becomes 0.17 as compared with an exponent of 0.27 obtained from data in reference 5 taken with a V-gutter at comparable inlet conditions. Both sets of data are shown in figure 17. These data indicate that the combustion efficiency of configuration VII is less sensitive to inlet pressure than that of the V-gutter alone.

## OPERATIONAL LIFE OF BLADES

The operational life of both types of blade was excellent for several hundreds of hours and did not limit the test duration except that at inlet air pressures above $1\frac{1}{4}$ atmospheres the molybdenum blades sometimes bent under ram pressure when incandescent.

## SUMMARY OF RESULTS

The following statements summarize the results obtained from operation of the 5-inch-diameter, connected-pipe, ram-jet combustor over the range of conditions investigated.

1. Flame-immersed blades improved combustion stability by extending the combustion limits, both rich and lean, and by decreasing the minimum permissible inlet pressure.

2. Flame-immersed blades improved combustion efficiency by improving the mixing of flame with fresh mixture downstream of a flame-holding baffle without upsetting the stability of the flame immediately behind the baffle.

3. Attempts at increasing the mixing of flame with fresh mixture by vortex generation upstream of the flame-holding baffle resulted in upsetting the combustion stability of the baffle, and lowered the efficiency.

4. The action of the flame-immersed blades used in this investigation on both combustion stability and efficiency was primarily aerodynamic inasmuch as the temperature of the blades showed secondary significance. Nonrefractory materials, externally cooled, were employed as immersed surfaces to improve combustion performance.

5. A blade configuration which mixed flame and fresh mixture in the combustor exhibited less sensitivity of combustion efficiency to inlet pressure than was found with a V-gutter flame holder alone.

6. Increasing the baffle width resulted in poorer combustion limits and efficiency.

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REFERENCES

1. Breitwieser, Roland: Performance of a Ram-Jet-Type Combustor with Flame Holders Immersed in the Combustion Zone. NACA RM E8F21, 1948.

2. Anon.: Survey of Bumblebee Activities. Bumblebee Series Rep. No. 121, Appl. Phys. Lab., Johns Hopkins Univ., Feb. 1950. (Contract NOrd 7386 with Bur. Ord., U.S. Navy.)

3. Male, Donald W., and Cervenka, Adolph J.: Design Factors for 4- by 8-Inch Ram-Jet Combustor. NACA RM E9F09, 1949.

4. Longwell, J. P.: Combustion Problems in Ram-Jet Design. Jour. Aero. Sci., vol. 16, no. 12, Dec. 1949, pp. 707-713; continued p. 760.

5. Reynolds, Thaine W., and Ingebo, Robert D.: Combustion Efficiency of Homogeneous Fuel-Air Mixtures in a 5-Inch Ram-Jet-Type Combustor. NACA RM E52I23, 1952.

TABLE I. - BASIC DATA FOR COMBUSTION LIMITS SHOWN IN FIGURES 5 TO 10

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, °R | Inlet velocity, V, ft/sec | Equivalence ratio | Blow-out | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 and 6 | 165 | 0.781 | 0.377 | 615 | 230.2 | 1.159 | Rich | Isopentane | Low | II |
| | 166 | .781 | .377 | 615 | 230.2 | .821 | Lean | | | |
| | 167 | .779 | .346 | 615 | 249.0 | .966 | Min. press. | | | |
| | 168 | .893 | .473 | 615 | 209.7 | .765 | Lean | | | |
| | 169 | .893 | .473 | 615 | 209.7 | 1.240 | Rich | | | |
| | 170 | .893 | .473 | 815 | 209.7 | 1.231 | Rich | | | |
| | 172 | 1.378 | .733 | 641 | 217.4 | 1.349 | Rich | | | |
| | 173 | 1.390 | .733 | 641 | 219.2 | .680 | Lean | | | |
| | 180 | 1.99 | 1.033 | 648 | 225.1 | .659 | Lean | | | |
| | 186 | 2.015 | 1.050 | 655 | 226.9 | 1.393 | Rich | | | |
| | 187 | .818 | .433 | 655 | 223.6 | .784 | Lean | | | |
| | 188 | .822 | .433 | 655 | 224.7 | 1.151 | Rich | | | |
| 5 | 266 | 1.200 | 0.616 | 643 | 225.7 | 1.265 | Rich | Isopentane | Low | I |
| | 267 | 1.200 | .616 | 660 | 231.6 | .901 | Lean | | | |
| | 268 | 1.200 | .616 | 661 | 232.0 | .879 | Lean | | | |
| | 269 | .990 | .566 | 652 | 205.4 | 1.038 | Min. press. | | | |
| | 270 | 1.340 | .716 | 637 | 214.8 | 1.271 | Rich | | | |
| | 271 | 1.360 | .716 | 665 | 227.6 | .830 | Lean | | | |
| | 274 | 2.025 | 1.016 | 640 | 229.9 | 1.335 | Rich | | | |
| | 275 | 2.025 | 1.016 | 667 | 239.6 | .769 | Lean | | | |
| | 276 | 1.200 | .716 | 645 | 194.8 | 1.298 | Rich | | | |
| 6(a) | 200 | 0.817 | 0.433 | 609 | 207.1 | 1.109 | Rich | Isopentane | Low | III |
| | 201 | .812 | .436 | 617 | 206.9 | .942 | Lean | | | |
| | 202 | .812 | .423 | 613 | 212.1 | 1.026 | Min. press. | | | |
| | 203 | 1.005 | .536 | 600 | 202.7 | 1.222 | Rich | | | |
| | 204 | 1.005 | .533 | 616 | 209.4 | .881 | Lean | | | |
| | 205 | 1.005 | .536 | 621 | 209.8 | .853 | Lean | | | |
| | 206 | 1.400 | .733 | 622 | 214.2 | 1.269 | Rich | | | |
| | 207 | 1.410 | .736 | 648 | 223.7 | .792 | Lean | | | |
| | 208 | 1.427 | 1.273 | 639 | 129.2 | 1.026 | Max. press. | | | |
| 6(b) | 131 | 1.013 | 0.543 | 644 | 216.7 | 0.855 | Lean | Isopentane | Low | IV |
| | 136 | 1.370 | .696 | 657 | 233.0 | .720 | Lean | | | |
| | 139 | 1.360 | .696 | 637 | 224.2 | 1.171 | Rich | | | |
| | 145 | 2.054 | 1.030 | 639 | 230.0 | 1.313 | Rich | | | |
| | 146 | 2.054 | 1.030 | 639 | 230.0 | .699 | Lean | | | |
| 6(c) | 189 | 0.918 | 0.483 | 601 | 205.9 | 1.141 | Rich | Isopentane | Low | V |
| | 190 | .936 | .483 | 609 | 212.7 | .968 | Lean | | | |
| | 191 | 1.001 | .533 | 609 | 208.2 | 1.194 | Rich | | | |
| | 192 | .992 | .533 | 624 | 209.4 | .920 | Lean | | | |
| | 193 | 1.422 | .733 | 606 | 212.0 | 1.289 | Rich | | | |
| | 194 | 1.447 | .733 | 640 | 227.8 | .798 | Lean | | | |
| | 195 | 1.970 | 1.040 | 651 | 222.4 | .755 | Lean | | | |
| | 196 | 1.973 | 1.033 | 623 | 214.6 | 1.347 | Rich | | | |
| 6(d) and 7 | 209 | 1.444 | 0.737 | 599 | 211.7 | 1.313 | Rich | Isopentane | Low | VI |
| | 210 | 1.434 | .737 | 627 | 220.0 | .745 | Lean | | | |
| | 211 | 1.224 | .640 | 610 | 210.4 | 1.289 | Rich | | | |
| | 212 | 1.224 | .637 | 637 | 220.7 | .740 | Lean | | | |
| | 213 | 1.429 | .737 | 615 | 215.1 | 1.321 | Rich | | | |
| | 214 | 1.429 | .737 | 643 | 224.9 | .732 | Lean | | | |
| | 215 | 1.998 | 1.040 | 618 | 214.2 | 1.390 | Rich | | | |
| | 216 | 1.998 | 1.037 | 654 | 227.3 | .687 | Lean | | | |
| | 232 | .641 | .367 | 606 | 190.9 | 1.161 | Rich | | | |
| | 241 | 1.995 | 1.040 | 663 | 229.4 | .677 | Lean | | | |

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TABLE I - BASIC DATA FOR COMBUSTION LIMITS SHOWN IN FIGURES 5 TO 10 - Continued

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, $^{\circ}R$ | Inlet velocity, V, ft/sec | Equivalence ratio | Blow-out | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 217 | 1.416 | 0.737 | 605 | 209.6 | 1.214 | Rich | Gasoline | Low | VI |
| | 218 | 1.425 | .737 | 639 | 222.9 | .702 | Lean | | | |
| | 219 | 1.204 | .637 | 616 | 210.0 | 1.246 | Rich | | | |
| | 220 | 1.230 | .637 | 642 | 223.6 | .732 | Lean | | | |
| | 221 | 1.448 | .737 | 620 | 219.7 | 1.222 | Rich | | | |
| | 222 | 2.015 | 1.037 | 625 | 219.0 | 1.225 | Rich | | | |
| | 223 | 2.010 | 1.033 | 658 | 230.9 | .633 | Lean | | | |
| | 224 | 1.183 | .633 | 611 | 206.0 | 1.232 | Rich | | | |
| | 225 | 1.182 | .633 | 636 | 214.2 | .762 | Lean | | | |
| | 226 | .802 | .433 | 610 | 203.8 | 1.199 | Rich | | | |
| | 227 | .819 | .433 | 611 | 208.4 | 1.154 | Rich | | | |
| | 228 | .819 | .433 | 624 | 212.9 | .855 | Lean | | | |
| | 229 | .640 | .367 | 591 | 185.8 | 1.178 | Rich | | | |
| | 230 | .638 | .367 | 603 | 189.1 | .946 | Lean | | | |
| | 231 | .643 | .330 | 610 | 214.4 | 1.061 | Rich | | | |
| | 233 | .639 | .367 | 620 | 194.7 | 0.908 | Lean | Isopentane | Low | VI |
| | 234 | .639 | .338 | 613 | 209.0 | 1.044 | Rich | | | |
| | 235 | .812 | .433 | 618 | 209.0 | 1.216 | Rich | | | |
| | 236 | .812 | .433 | 634 | 214.4 | .867 | Lean | | | |
| | 237 | .812 | .433 | 635 | 214.8 | .847 | Lean | | | |
| | 238 | 1.170 | .633 | 618 | 206.0 | 1.297 | Rich | | | |
| | 239 | 1.177 | .640 | 644 | 213.6 | .760 | Lean | | | |
| | 240 | 1.980 | 1.033 | 629 | 217.5 | 1.375 | Rich | | | |
| 8 and 10 | 457 | 1.955 | 1.000 | 650 | 229.2 | 0.741 | Lean | Gasoline | High | I |
| | 458 | 1.940 | 1.000 | 626 | 219.0 | 1.368 | Rich | | | |
| | 459 | 1.390 | .700 | 654 | 234.2 | .771 | Lean | | | |
| | 460 | 1.365 | .700 | 636 | 223.7 | 1.294 | Rich | | | |
| | 461 | 1.150 | .600 | 655 | 226.4 | .815 | Lean | | | |
| | 462 | 1.190 | .600 | 632 | 226.1 | 1.278 | Rich | | | |
| | 463 | 1.190 | .600 | 633 | 226.5 | 1.252 | Rich | | | |
| | 464 | 1.175 | .600 | 656 | 231.7 | .798 | Lean | | | |
| | 465 | 1.000 | .500 | 654 | 235.9 | .816 | Lean | | | |
| | 466 | 1.005 | .500 | 636 | 230.6 | 1.220 | Rich | | | |
| | 467 | .890 | .450 | 653 | 232.9 | .866 | Lean | | | |
| | 468 | .890 | .450 | 639 | 227.9 | 1.152 | Rich | | | |
| | 469 | .890 | .450 | 638 | 227.6 | 1.180 | Rich | | | |
| | 470 | .885 | .400 | 649 | 259.0 | 1.008 | Min. press. | | | |
| | 471 | 0.985 | 0.500 | 650 | 231.0 | 0.711 | Lean | Gasoline | High | II |
| | 472 | .995 | .500 | 627 | 225.1 | 1.276 | Rich | | | |
| | 473 | .885 | .450 | 656 | 232.7 | .724 | Lean | | | |
| | 474 | .880 | .450 | 631 | 222.6 | 1.274 | Rich | | | |
| | 475 | .880 | .450 | 634 | 223.6 | 1.254 | Lean | | | |
| | 477 | .760 | .400 | 640 | 219.4 | 1.233 | Rich | | | |
| | 478 | .755 | .313 | 655 | 284.7 | .982 | Min. press. | | | |
| | 479 | .760 | .326 | 669 | 280.7 | .882 | Min. press. | | | |
| | 480 | .825 | .400 | 677 | 251.8 | .742 | Lean | | | |
| | 481 | .850 | .330 | 668 | 310.4 | .873 | Min. press. | | | |
| | 482 | 1.185 | .600 | 683 | 243.3 | .664 | Lean | | | |
| | 483 | 1.150 | .600 | 649 | 224.3 | 1.377 | Rich | | | |
| | 484 | 1.375 | .700 | 687 | 243.4 | .648 | Lean | | | |
| | 485 | 1.360 | .700 | 652 | 228.5 | 1.382 | Rich | | | |
| | 486 | 1.930 | 1.000 | 683 | 237.8 | .634 | Lean | | | |
| | 487 | 1.940 | 1.000 | 641 | 224.3 | 1.401 | Rich | | | |

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TABLE I. - BASIC DATA FOR COMBUSTION LIMITS SHOWN IN FIGURES 5 TO 10 - Concluded

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, $^{\circ}R$ | Inlet velocity, V, ft/sec | Equivalence ratio | Blow-out | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 and 10 | 396 | 1.914 | 1.000 | 670 | 231.3 | 0.660 | Lean | Gasoline | High | I |
| | 400 | 1.914 | 1.000 | 636 | 219.6 | 1.398 | Rich | | | |
| | 401 | 1.425 | .700 | 670 | 246.0 | .684 | Lean | | | |
| | 402 | 1.425 | .700 | 639 | 234.6 | 1.347 | Rich | | | |
| | 406 | 1.181 | .600 | 660 | 254.3 | .692 | Lean | | | |
| | 407 | 1.180 | .600 | 659 | 253.7 | .717 | Lean | | | |
| | 408 | 1.170 | .600 | 628 | 220.9 | 1.353 | Rich | | | |
| | 409 | .975 | .500 | 660 | 252.2 | .726 | Lean | | | |
| | 410 | .975 | .500 | 635 | 223.4 | 1.257 | Rich | | | |
| | 411 | .875 | .450 | 660 | 231.5 | .767 | Lean | | | |
| | 412 | .868 | .450 | 638 | 222.0 | 1.241 | Rich | | | |
| | 413 | .770 | .400 | 639 | 221.8 | 1.206 | Rich | | | |
| | 414 | .768 | .400 | 659 | 228.2 | .798 | Lean | | | |
| | 415 | .768 | .400 | 659 | 228.2 | .803 | Lean | | | |
| | 416 | .765 | .343 | 652 | 262.1 | 1.019 | Min. press. | | | |
| | 417 | .770 | .358 | 651 | 252.4 | 1.110 | Min. press. | | | |
| | 418 | .755 | .333 | 659 | 269.3 | .954 | Min. press. | | | |
| | 419 | .768 | .350 | 664 | 262.8 | 1.014 | Min. press. | | | |
| | 420 | 1.608 | .850 | 659 | 224.9 | 1.394 | Rich | | | |
| | 421 | 1.610 | .850 | 693 | 256.7 | .652 | Lean | | | |
| | 422 | 1.650 | .850 | 693 | 242.6 | .652 | Lean | | | |
| | 423 | 1.655 | .850 | 683 | 239.9 | .672 | Lean | | | |
| 9 | 577 | 1.185 | 0.600 | 649 | 231.2 | 0.886 | Lean | Gasoline | High | I[a] |
| | 578 | 1.190 | .600 | 632 | 226.1 | 1.244 | Rich | | | |
| | 579 | .985 | .500 | 639 | 227.0 | 1.062 | Lean | | | |
| | 580 | .985 | .500 | 640 | 227.4 | 1.088 | Rich | | | |
| | 581 | .985 | .510 | 641 | 223.3 | 1.074 | Min. press. | | | |
| | 582 | 1.090 | .550 | 648 | 231.6 | .952 | Lean | | | |
| | 583 | 1.090 | .550 | 639 | 228.4 | 1.173 | Rich | | | |
| | 584 | 1.720 | .850 | 675 | 246.3 | .772 | Lean | | | |
| | 585 | 1.720 | .850 | 649 | 236.9 | 1.316 | Rich | | | |
| | 586 | 1.990 | 1.000 | 675 | 242.3 | .760 | Lean | | | |
| | 587 | 1.995 | 1.000 | 647 | 232.8 | 1.342 | Rich | | | |
| | 588 | 1.985 | 1.000 | 647 | 228.3 | 1.342 | Rich | | | |
| 10 | 424 | 1.920 | 1.000 | 656 | 227.1 | 0.756 | Lean | Gasoline | High | II[b] |
| | 425 | 1.920 | 1.000 | 627 | 217.1 | 1.380 | Rich | | | |
| | 426 | 1.370 | .700 | 630 | 222.4 | 1.314 | Rich | | | |
| | 427 | 1.365 | .700 | 630 | 221.6 | 1.324 | Rich | | | |
| | 428 | 1.370 | .700 | 651 | 229.8 | .888 | Lean | | | |
| | 429 | 1.350 | .700 | 648 | 225.4 | .934 | Lean | | | |
| | 430 | 1.198 | .600 | 650 | 234.1 | .904 | Lean | | | |
| | 431 | 1.202 | .600 | 629 | 227.3 | 1.335 | Rich | | | |
| | 432 | .955 | .500 | 658 | 226.7 | .816 | Lean | | | |
| | 433 | .950 | .500 | 638 | 218.6 | 1.228 | Rich | | | |
| | 434 | .780 | .393 | 649 | 232.2 | .999 | Min. press. | | | |
| | 435 | .780 | .380 | 649 | 240.2 | .999 | Min. press. | | | |
| | 436 | 1.130 | .600 | 659 | 223.8 | .789 | Lean | | | |
| | 437 | 1.130 | .600 | 635 | 215.7 | 1.292 | Rich | | | |

[a]V-gutter 2" wide by 2" high.
[b]Cooled blades.

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TABLE II. - BASIC DATA FOR COMBUSTION EFFICIENCIES SHOWN IN FIGURES 11 TO 16

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, $^{\circ}R$ | Inlet velocity, V, ft/sec | Equivalence ratio | Efficiency, $\eta$ | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 11(a) | 59 | 3.80 | 2.003 | 684 | 234.0 | 0.769 | 65.2 | Isopentane | Low | II |
| | 60 | 3.80 | 2.013 | 685 | 233.2 | .714 | 63.8 | | | |
| | 61 | 3.80 | 2.013 | 687 | 234.0 | .660 | 61.6 | | | |
| | 62 | 3.79 | 2.010 | 680 | 231.2 | .829 | 69.1 | | | |
| | 63 | 3.79 | 2.010 | 677 | 230.2 | .885 | 70.9 | | | |
| | 64 | 3.79 | 2.000 | 674 | 230.4 | .942 | 71.2 | | | |
| | 65 | 3.79 | 2.000 | 672 | 229.6 | .997 | 70.9 | | | |
| | 66 | 3.79 | 2.000 | 668 | 228.3 | 1.055 | 66.6 | | | |
| | 67 | 3.79 | 2.000 | 666 | 227.7 | 1.108 | 62.8 | | | |
| | 68 | 3.79 | 1.993 | 681 | 233.6 | .771 | 67.8 | | | |
| | 69 | 3.79 | 2.000 | 678 | 231.8 | .885 | 72.2 | | | |
| | 70 | 3.79 | 2.000 | 676 | 231.0 | .942 | 73.4 | | | |
| | 71 | 3.79 | 2.000 | 684 | 233.8 | .716 | 64.6 | | | |
| | 72 | 3.85 | 2.000 | 673 | 233.8 | 0.760 | 62.1 | Isopentane | Low | I |
| | 73 | 3.84 | 2.000 | 670 | 232.1 | .818 | 65.2 | | | |
| | 74 | 3.84 | 2.000 | 667 | 231.1 | .873 | 69.6 | | | |
| | 75 | 3.84 | 1.993 | 663 | 230.5 | .930 | 70.7 | | | |
| | 76 | 3.84 | 2.010 | 660 | 227.6 | .985 | 70.4 | | | |
| | 77 | 3.84 | 2.010 | 657 | 226.5 | 1.040 | 66.1 | | | |
| | 78 | 3.84 | 2.007 | 655 | 226.0 | 1.096 | 59.3 | | | |
| | 79 | 3.84 | 2.007 | 660 | 228.0 | .985 | 70.1 | | | |
| | 80 | 3.84 | 2.000 | 664 | 229.9 | .930 | 70.8 | | | |
| | 81 | 3.84 | 2.000 | 668 | 231.3 | .873 | 69.8 | | | |
| | 82 | 3.84 | 2.000 | 674 | 233.6 | .760 | 63.9 | | | |
| | 83 | 3.84 | 2.000 | 674 | 233.6 | .708 | (1) | | | |
| 11(b) | 25 | 1.060 | 0.520 | 633 | 232.7 | 0.777 | 52.2 | Isopentane | Low | I |
| | 26 | 1.055 | .516 | 626 | 230.5 | .896 | 49.7 | | | |
| | 27 | 1.060 | .520 | 621 | 228.4 | 1.005 | 46.9 | | | |
| | 28 | 1.060 | .520 | 625 | 230.0 | .950 | 48.7 | | | |
| | 29 | 1.068 | .520 | 628 | 232.7 | .835 | 50.3 | | | |
| | 30 | 1.068 | .523 | 619 | 227.9 | 1.053 | 42.6 | | | |
| | 31 | 1.068 | .523 | 618 | 227.7 | 1.110 | 40.0 | | | |
| | 32 | 1.072 | 0.520 | 614 | 228.3 | 0.992 | 47.6 | Isopentane | Low | II |
| | 33 | 1.058 | .523 | 614 | 224.1 | .950 | 50.6 | | | |
| | 34 | 1.070 | .516 | 617 | 230.7 | .884 | 52.5 | | | |
| | 35 | 1.067 | .516 | 619 | 230.7 | .827 | 54.0 | | | |
| | 36 | 1.066 | .523 | 623 | 229.1 | .773 | 56.4 | | | |
| | 37 | 1.069 | .520 | 612 | 217.1 | 1.047 | 42.0 | | | |
| | 38 | 1.068 | .520 | 609 | 226.0 | 1.116 | 38.2 | | | |
| | 39 | 1.068 | .520 | 616 | 228.2 | 1.052 | 42.0 | | | |
| | 40 | 1.068 | .520 | 621 | 230.5 | .940 | 49.1 | | | |
| | 41 | 1.068 | .516 | 626 | 233.6 | .826 | 52.4 | | | |
| 11(c) and 12 | 11 | 2.020 | 1.326 | 728 | 200.1 | 0.821 | 76.6 | Isopentane | Low | I |
| | 12 | 2.030 | 1.343 | 721 | 196.5 | 1.018 | 76.7 | | | |
| | 13 | 2.005 | 1.326 | 710 | 193.5 | 1.261 | 57.0 | | | |
| | 14 | 2.025 | 1.330 | 729 | 200.2 | .911 | 81.4 | | | |
| | 15 | 2.000 | 1.346 | 739 | 198.1 | .721 | 79.2 | | | |
| | 17 | 2.020 | 1.330 | 718 | 196.8 | 0.811 | 77.2 | Isopentane | Low | II |
| | 18 | 2.026 | 1.326 | 711 | 196.0 | 1.020 | 75.8 | | | |
| | 19 | 2.009 | 1.333 | 709 | 192.8 | 1.137 | 69.7 | | | |
| | 20 | 2.000 | 1.333 | 723 | 195.8 | .925 | 78.9 | | | |
| | 21 | 1.990 | 1.340 | 737 | 197.4 | .719 | 80.6 | | | |
| | 22 | 1.985 | 1.343 | 714 | 190.4 | 1.273 | 57.2 | | | |

[1]Lean blow-out.

TABLE II. - BASIC DATA FOR COMBUSTION EFFICIENCIES SHOWN IN FIGURES 11 TO 16 - Continued

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, °R | Inlet velocity, V, ft/sec | Equivalence ratio | Efficiency, $\eta$ | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 42 | 2.065 | 1.336 | 700 | 195.2 | 1.002 | 84.2 | Isopentane | Low | VII |
| | 43 | 2.040 | 1.333 | 699 | 193.0 | 1.121 | 77.3 | | | |
| | 44 | 2.025 | 1.326 | 696 | 191.7 | 1.238 | 67.0 | | | |
| | 45 | 2.020 | 1.330 | 711 | 194.8 | 1.023 | 82.6 | | | |
| | 46 | 2.015 | 1.333 | 721 | 196.5 | .919 | 89.1 | | | |
| | 47 | 2.010 | 1.333 | 730 | 198.5 | .815 | 92.6 | | | |
| | 48 | 2.010 | 1.333 | 737 | 200.5 | .711 | 92.4 | | | |
| | 49 | 2.005 | 1.340 | 728 | 196.6 | 1.031 | 83.8 | | | |
| | 50 | 2.025 | 1.333 | 725 | 198.6 | 1.128 | 75.7 | | | |
| | 51 | 2.025 | 1.333 | 717 | 196.4 | 1.238 | 64.3 | | | |
| | 52 | 2.025 | 1.333 | 728 | 189.4 | 1.021 | 84.6 | | | |
| | 53 | 2.025 | 1.340 | 740 | 201.8 | .815 | 97.1 | | | |
| | 54 | 2.025 | 1.333 | 748 | 204.9 | .713 | 95.5 | | | |
| | 244 | 2.145 | 1.333 | 696 | 202.1 | 0.863 | 24.3 | Isopentane | Low | VIII |
| | 245 | 2.160 | 1.347 | 704 | 203.5 | .759 | 26.5 | | | |
| | 246 | 2.160 | 1.357 | 704 | 202.2 | .794 | 27.4 | | | |
| | 247 | 2.195 | 1.333 | 704 | 209.1 | .681 | (b) | | | |
| | 248 | 2.180 | 1.333 | 704 | 207.6 | .908 | (a) | | | |
| | 249 | 2.185 | 1.333 | 710 | 210.0 | .798 | 25.2 | | | |
| | 250 | 2.185 | 1.333 | 710 | 210.0 | .711 | (b) | | | |
| 13 and 14 | 359 | 1.735 | 1.000 | 651 | 203.9 | 0.774 | 56.0 | Gasoline | High | I |
| | 360 | 1.735 | 1.000 | 651 | 203.9 | .732 | (b) | | | |
| | 361 | 1.725 | 1.000 | 646 | 201.0 | .864 | 62.9 | | | |
| | 362 | 1.735 | 1.000 | 643 | 201.4 | .846 | 63.9 | | | |
| | 363 | 1.720 | 1.000 | 641 | 198.9 | 1.044 | 64.6 | | | |
| | 364 | 1.725 | 1.000 | 639 | 198.8 | 1.127 | 61.9 | | | |
| | 365 | 1.730 | 1.000 | 636 | 198.5 | 1.217 | 57.1 | | | |
| 13 | 589 | 1.715 | 1.000 | 654 | 202.3 | 1.184 | 53.5 | Gasoline | High | I[c] |
| | 590 | 1.710 | 1.000 | 656 | 202.3 | 1.116 | 58.4 | | | |
| | 591 | 1.715 | 1.003 | 659 | 203.2 | 1.047 | 60.9 | | | |
| | 592 | 1.720 | 1.000 | 662 | 205.5 | .976 | 61.0 | | | |
| | 593 | 1.715 | 1.000 | 666 | 206.2 | .914 | 60.9 | | | |
| | 594 | 1.715 | 1.000 | 669 | 207.1 | .850 | 59.6 | | | |
| | 595 | 1.715 | 1.000 | 669 | 207.1 | .783 | (b) | | | |
| | 596 | 1.715 | 1.000 | 565 | 202.9 | 1.184 | 55.3 | | | |
| | 597 | 1.720 | 1.000 | 651 | 202.1 | 1.248 | 51.5 | | | |
| | 598 | 1.715 | 1.000 | 647 | 200.3 | 1.318 | 46.6 | | | |
| | 599 | 1.715 | 1.000 | 647 | 200.3 | 1.353 | (a) | | | |
| | 600 | 1.725 | 1.000 | 667 | 207.7 | .939 | 60.2 | | | |
| | 601 | 1.720 | 1.000 | 662 | 205.5 | 1.012 | 61.9 | | | |
| 14 | 345 | 1.660 | 1.000 | 679 | 203.4 | 0.765 | 85.4 | Gasoline | High | VII |
| | 346 | 1.655 | 1.000 | 679 | 202.8 | .724 | 83.8 | | | |
| | 347 | 1.655 | 1.000 | 679 | 202.8 | .697 | (b) | | | |
| | 348 | 1.675 | 1.000 | 673 | 203.3 | .801 | 86.4 | | | |
| | 349 | 1.670 | 1.000 | 670 | 201.8 | .850 | 86.5 | | | |
| | 350 | 1.675 | 1.000 | 666 | 201.2 | .891 | 86.6 | | | |
| | 351 | 1.680 | 1.000 | 663 | 201.0 | .932 | 86.4 | | | |
| | 352 | 1.685 | 1.000 | 659 | 200.3 | .974 | 85.6 | | | |
| | 353 | 1.690 | 1.000 | 656 | 199.9 | 1.015 | 84.3 | | | |
| | 354 | 1.680 | 1.013 | 652 | 195.0 | 1.069 | 81.7 | | | |
| | 355 | 1.700 | 1.013 | 650 | 196.7 | 1.100 | 78.9 | | | |
| | 356 | 1.690 | 1.023 | 644 | 191.9 | 1.153 | 72.9 | | | |
| | 357 | 1.705 | 1.023 | 641 | 192.7 | 1.189 | 69.5 | | | |
| | 381 | 1.670 | 1.000 | 659 | 198.6 | .892 | 80.1 | | | |
| | 382 | 1.675 | 1.000 | 663 | 200.4 | 0.846 | 82.1 | Gasoline | High | VII[d] |
| | 383 | 1.665 | 1.000 | 667 | 200.3 | .808 | 82.7 | | | |
| | 384 | 1.665 | 1.000 | 670 | 201.4 | .763 | 82.3 | | | |
| | 385 | 1.665 | 1.000 | 670 | 201.4 | .748 | (b) | | | |
| | 386 | 1.655 | 1.000 | 666 | 199.0 | .994 | 80.8 | | | |
| | 387 | 1.655 | 1.000 | 662 | 197.8 | 1.084 | 77.6 | | | |
| | 388 | 1.665 | 1.000 | 658 | 197.7 | 1.171 | 70.3 | | | |
| | 389 | 1.655 | 1.000 | 654 | 195.4 | 1.273 | 61.0 | | | |
| | 390 | 1.655 | 1.000 | 654 | 195.4 | 1.321 | (a) | | | |
| | 391 | 1.650 | 1.000 | 668 | 199.0 | 1.040 | 80.0 | | | |
| | 392 | 1.660 | 1.000 | 672 | 201.3 | .942 | 83.6 | | | |
| | 393 | 1.660 | 1.000 | 664 | 198.8 | 1.129 | 73.0 | | | |
| | 394 | 1.655 | 1.000 | 660 | 197.2 | 1.228 | 65.2 | | | |
| | 395 | 1.655 | 1.000 | 660 | 197.2 | 1.316 | (a) | | | |

[a]Rich blow-out.
[b]Lean blow-out.
[c]V-gutter 2" wide by 2" high.
[d]Cooled blades.

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TABLE II. - BASIC DATA FOR COMBUSTION EFFICIENCIES SHOWN IN FIGURES 11 TO 16 - Concluded

| Figure | Run | Air flow, $M_a$, lb/sec | Inlet static pressure, P, atm | Inlet mixture temperature, T, °R | Inlet velocity, V, ft/sec | Equivalence ratio | Efficiency, $\eta$ | Fuel | Injection-system pressure | Configuration |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 and 16 | 623 | 1.145 | 0.666 | 658 | 203.8 | 1.048 | 69.4 | Gasoline | High | VII |
| | 624 | 1.145 | .666 | 654 | 202.6 | 1.110 | 66.7 | | | |
| | 625 | 1.145 | .666 | 650 | 201.4 | 1.172 | 62.0 | | | |
| | 626 | 1.145 | .666 | 650 | 201.4 | 1.240 | (a) | | | |
| | 627 | 1.150 | .666 | 655 | 203.9 | 1.044 | 70.3 | | | |
| | 628 | 1.145 | .666 | 658 | 203.8 | .986 | 74.4 | | | |
| | 629 | 1.145 | .666 | 660 | 204.6 | .924 | 77.2 | | | |
| | 630 | 1.145 | .666 | 662 | 205.2 | .862 | 78.5 | | | |
| | 631 | 1.160 | .666 | 665 | 208.9 | .790 | 78.4 | | | |
| 15 | 366 | 1.125 | 0.666 | 653 | 198.7 | 0.944 | 58.3 | Gasoline | High | I |
| | 367 | 1.120 | .666 | 652 | 197.7 | .885 | 57.7 | | | |
| | 368 | 1.120 | .666 | 654 | 198.3 | .819 | 53.8 | | | |
| | 369 | 1.120 | .666 | 654 | 198.3 | .777 | (b) | | | |
| | 370 | 1.120 | .666 | 647 | 196.2 | 1.008 | 59.3 | | | |
| | 371 | 1.110 | .666 | 644 | 193.5 | 1.081 | 59.7 | | | |
| | 372 | 1.120 | .666 | 641 | 194.4 | 1.133 | 57.3 | | | |
| | 373 | 1.120 | .666 | 638 | 193.5 | 1.201 | 53.1 | | | |
| | 374 | 1.120 | .666 | 635 | 192.6 | 1.264 | 49.6 | | | |
| | 375 | 1.120 | .666 | 635 | 192.6 | 1.339 | (a) | | | |
| 16 | 632 | 1.160 | 0.666 | 665 | 208.9 | 0.734 | (b) | Gasoline | High | VII |
| | 633 | .765 | .443 | 653 | 203.3 | 1.100 | 64.1 | | | |
| | 634 | .765 | .450 | 653 | 200.2 | 1.149 | (a) | | | |
| | 635 | .760 | .450 | 652 | 198.8 | 1.058 | 65.7 | | | |
| | 636 | .765 | .453 | 653 | 198.9 | 1.002 | 66.9 | | | |
| | 637 | .760 | .450 | 656 | 199.8 | .954 | 69.7 | | | |
| | 638 | .760 | .450 | 656 | 199.8 | .954 | (b) | | | |
| | 640 | 0.850 | 0.500 | 656 | 201.3 | 1.078 | 65.1 | Gasoline | High | VII |
| | 641 | .850 | .500 | 654 | 200.5 | 1.118 | 64.0 | | | |
| | 642 | .850 | .500 | 651 | 199.8 | 1.162 | 61.5 | | | |
| | 643 | .850 | .500 | 651 | 199.8 | 1.206 | 58.6 | | | |
| | 644 | .850 | .500 | 651 | 199.8 | 1.245 | (a) | | | |
| | 645 | .850 | .500 | 660 | 202.5 | 1.078 | 65.9 | | | |
| | 646 | .850 | .500 | 661 | 202.7 | 1.035 | 69.1 | | | |
| | 647 | .850 | .500 | 662 | 203.1 | .990 | 70.1 | | | |
| | 648 | .850 | .500 | 663 | 203.4 | .946 | 71.6 | | | |
| | 649 | .850 | .503 | 665 | 202.7 | .902 | 72.6 | | | |
| | 650 | .850 | .503 | 668 | 203.5 | .854 | 73.2 | | | |
| | 651 | .850 | .500 | 668 | 204.8 | .838 | (b) | | | |
| | 652 | 1.740 | 1.000 | 696 | 218.6 | 0.771 | 79.7 | Gasoline | High | VII |
| | 653 | 1.735 | 1.000 | 691 | 216.2 | .819 | 82.2 | | | |
| | 654 | 1.735 | 1.000 | 687 | 215.7 | .860 | 80.8 | | | |
| | 655 | 1.735 | 1.000 | 685 | 214.5 | .903 | 82.0 | | | |
| | 656 | 1.740 | 1.000 | 682 | 214.0 | .944 | 81.2 | | | |
| | 657 | 1.740 | 1.000 | 679 | 213.2 | .988 | 79.1 | | | |
| | 658 | 1.740 | 1.000 | 677 | 212.6 | 1.032 | 76.7 | | | |
| | 659 | 1.740 | 1.000 | 672 | 211.0 | 1.120 | 69.9 | | | |
| | 660 | 1.740 | 1.000 | 668 | 209.7 | 1.212 | 62.0 | | | |
| | 661 | 1.745 | 1.000 | 662 | 208.3 | 1.298 | 53.2 | | | |
| | 662 | 1.745 | 1.000 | 662 | 208.3 | 1.344 | (a) | | | |
| | 663 | 1.740 | 1.000 | 687 | 215.6 | .771 | 81.4 | | | |
| | 664 | 1.740 | 1.000 | 688 | 215.9 | .730 | 80.8 | | | |
| | 665 | 1.740 | 1.000 | 688 | 215.9 | .686 | (b) | | | |
| | 666 | 1.440 | 0.833 | 682 | 212.6 | 0.732 | 77.5 | Gasoline | High | VII |
| | 667 | 1.450 | .833 | 676 | 212.3 | 1.005 | 76.3 | | | |
| | 668 | 1.440 | .833 | 672 | 209.5 | 1.088 | 71.8 | | | |
| | 669 | 1.430 | .833 | 668 | 206.9 | 1.174 | 65.2 | | | |
| | 670 | 1.440 | .833 | 664 | 207.1 | 1.246 | 57.2 | | | |

[a]Rich blow-out.
[b]Lean blow-out.

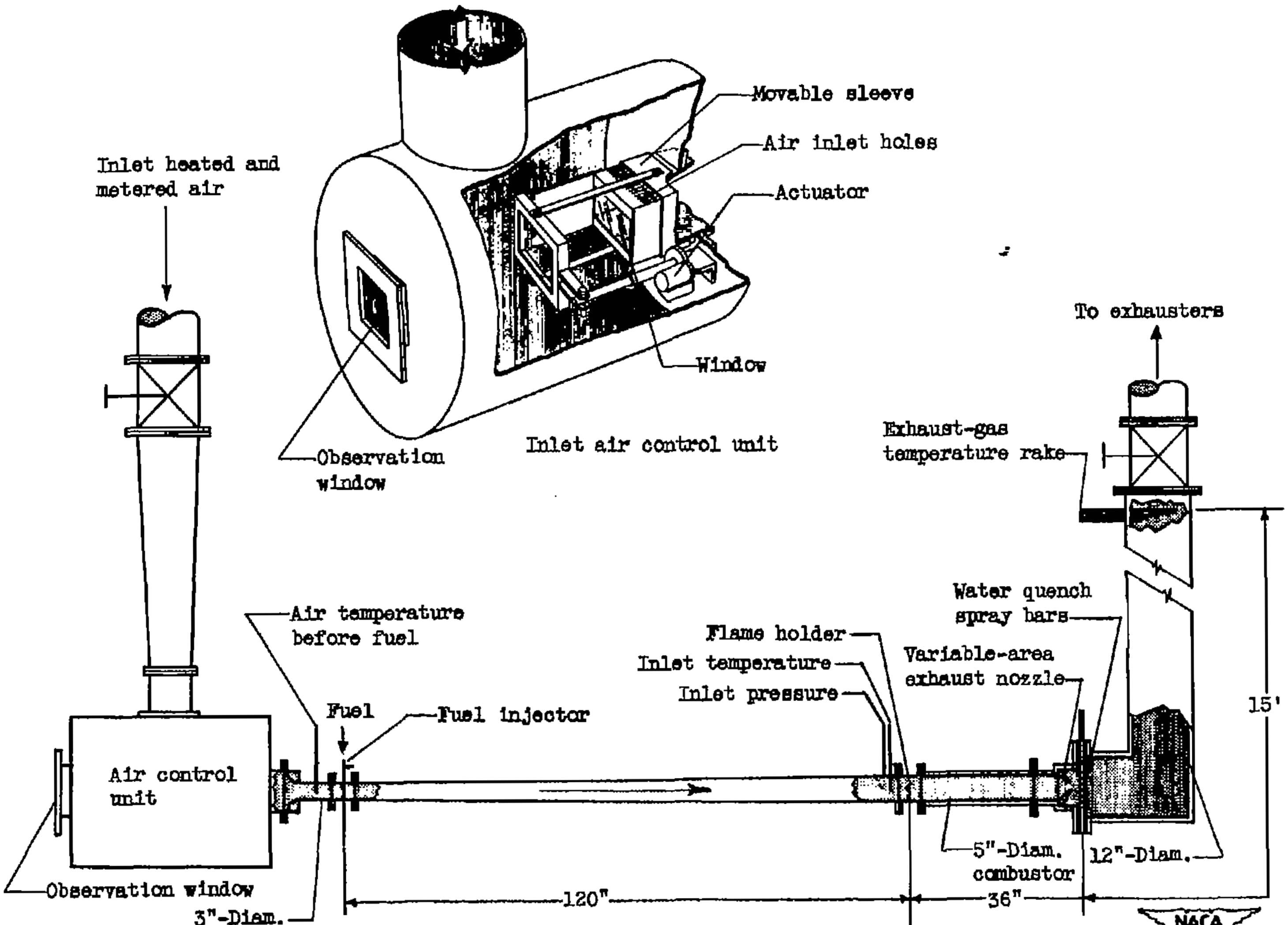



Figure 1. - Schematic illustration of 5-inch ram-jet combustor setup.

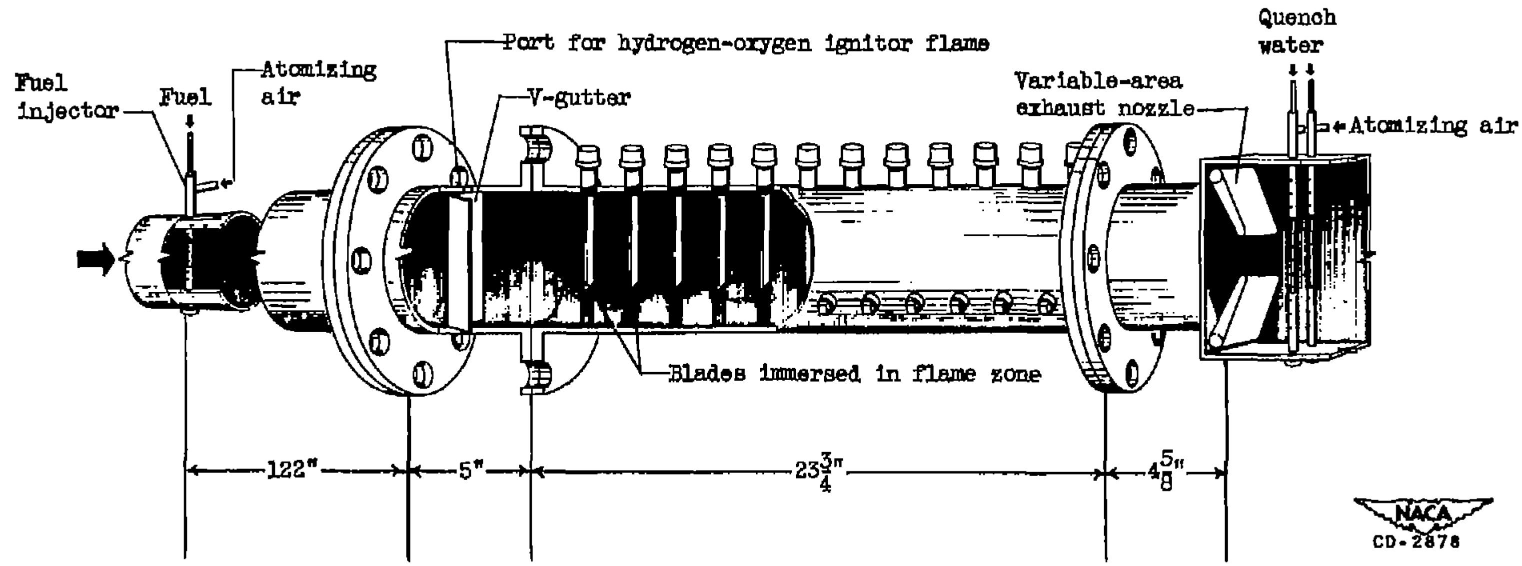
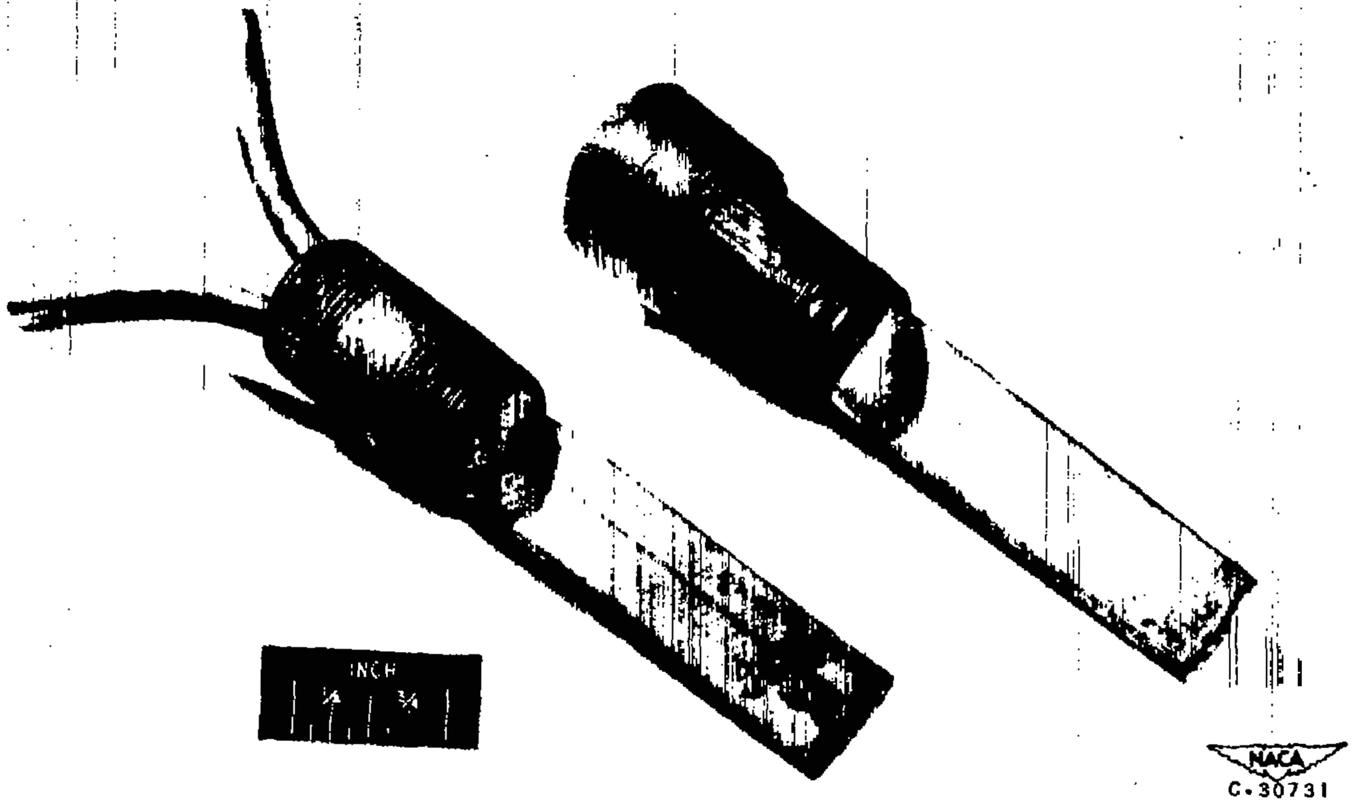



Figure 2. - Five-inch-diameter, connected-pipe, ram-jet combustor.




(a) Inconel blade, internally water cooled.

(b) Molybdenum blade, refractory and oxidation resistant up to 3000° F.

Figure 3. - Photograph of two types of flame-immersed blade used in 5-inch-diameter ram-jet combustor.

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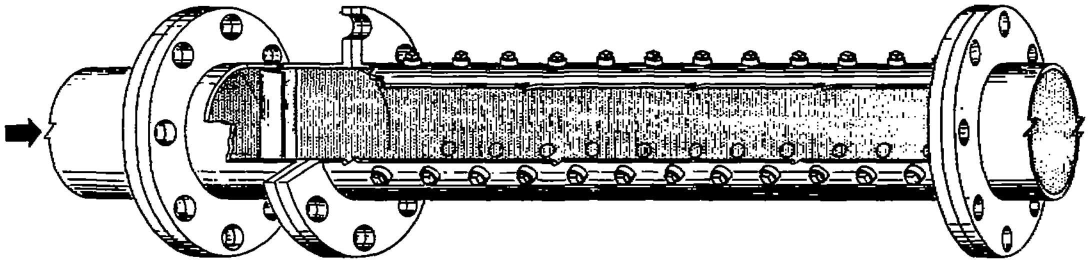
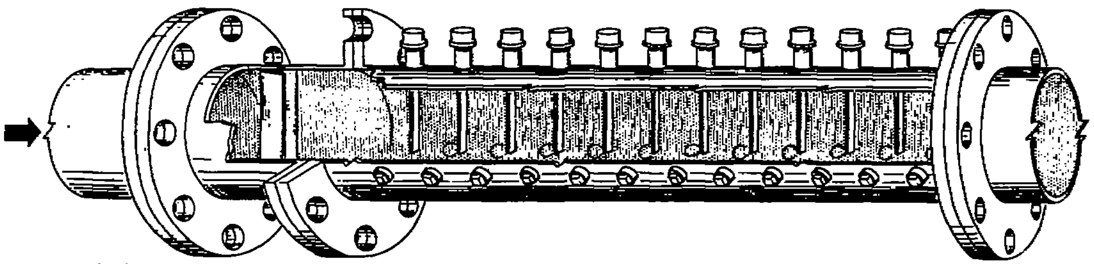
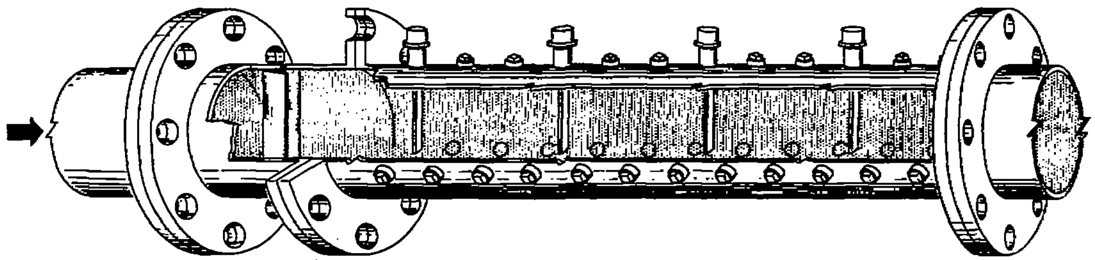


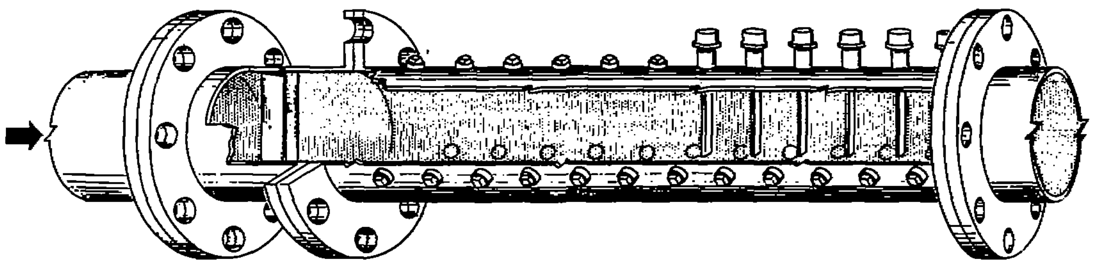
(a) Configuration I; V-gutter alone.



(b) Configuration II; 12 blades in line and perpendicular to axis.



(c) Configuration III; blades in positions 1, 4, 7, and 10.



(d) Configuration IV; blades in positions 7 to 12.

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Figure 4. - Various geometrical configurations used in investigation.

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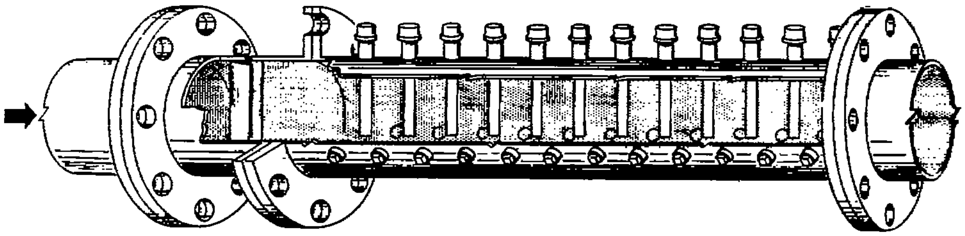
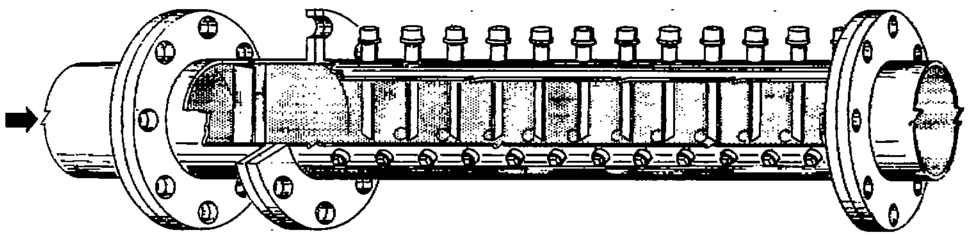
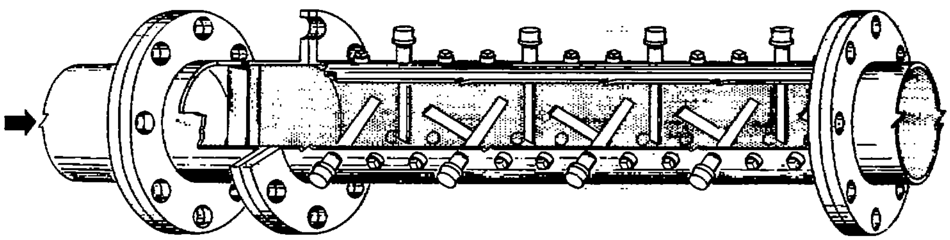


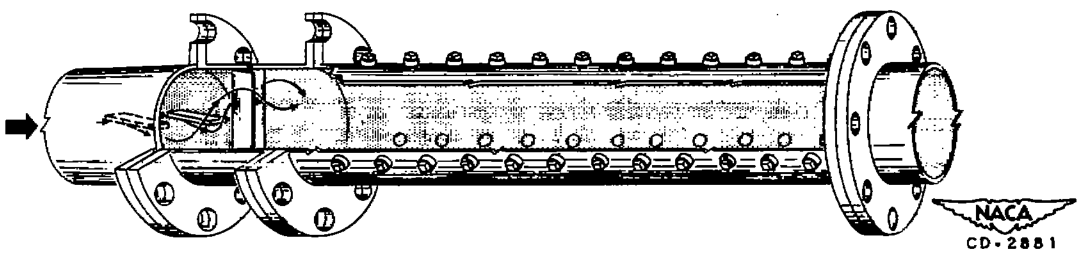
(e) Configuration V; 12 blades in line and parallel to axis.



(f) Configuration VI; 12 blades turned 45° to axis and alternating.



(g) Configuration VII; 12 blades positioned for mixing.




(h) Configuration VIII; vortex generators upstream of V-gutter.

Figure 4. - Concluded. Various geometrical configurations used in investigation.

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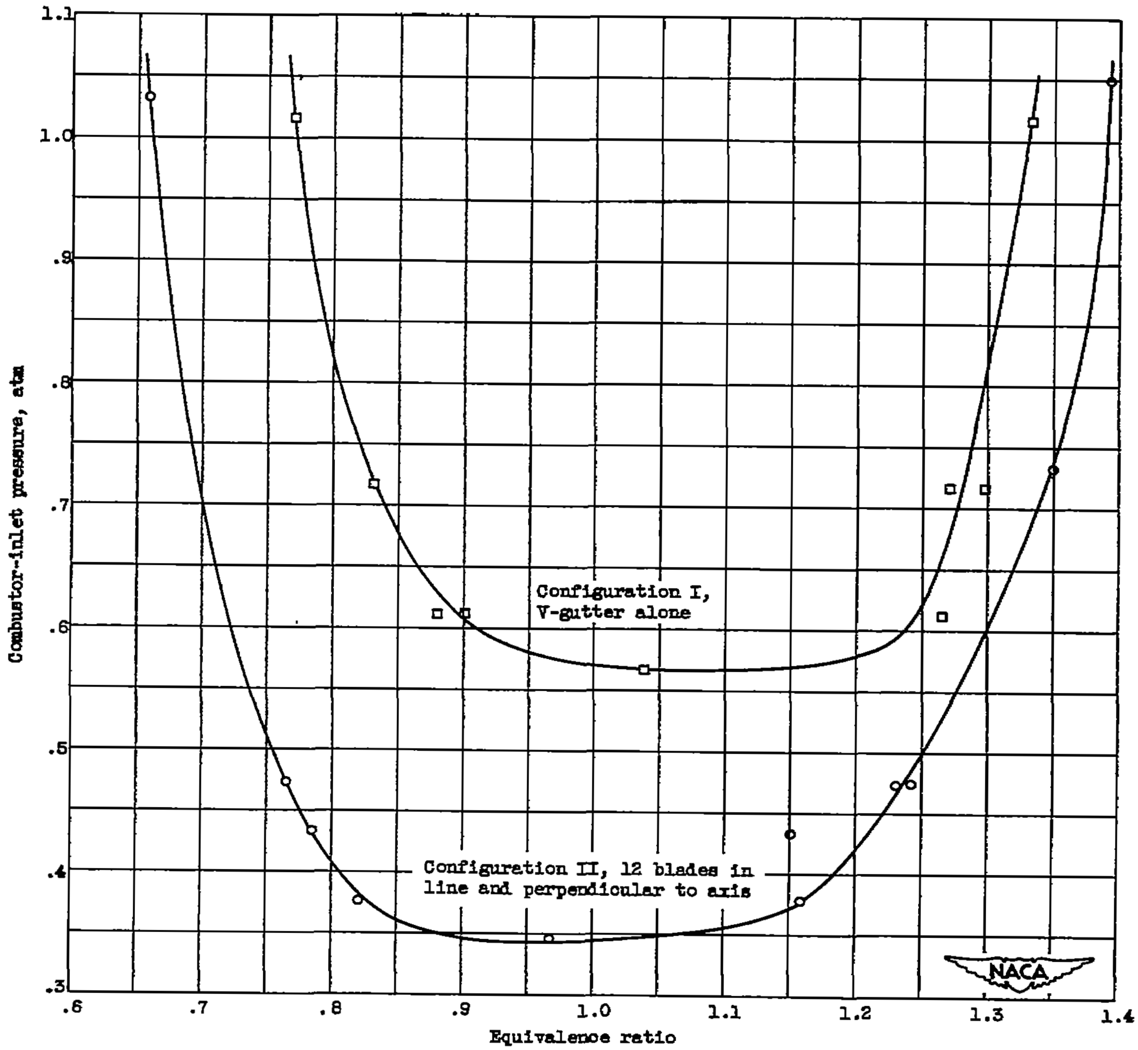


Figure 5. - Comparison of combustion limits of configurations I and II. Inlet conditions: temperature, 200° F; velocity, 220 feet per second. Fuel, isopentane with low-pressure injection.

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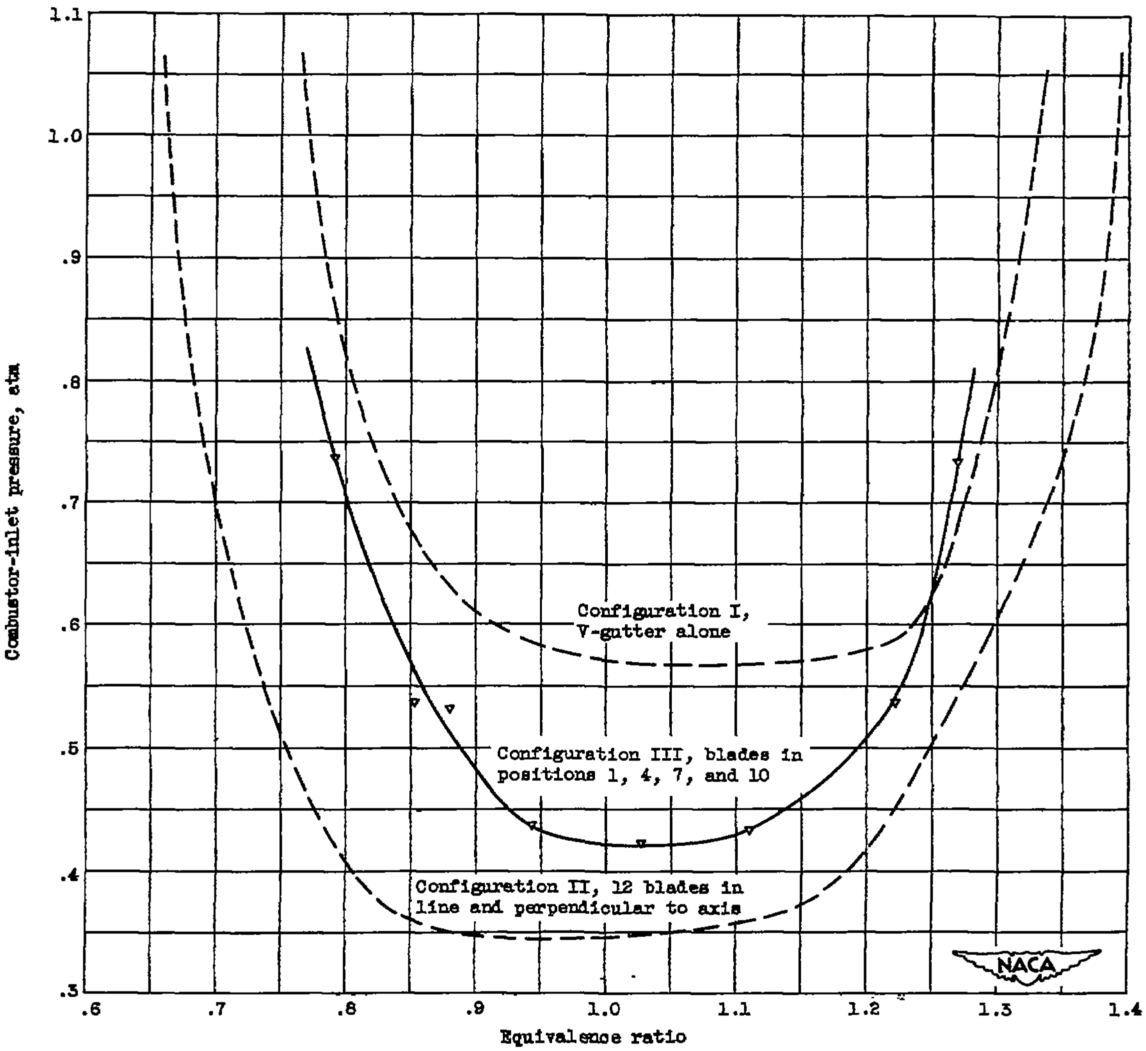


(a) Configuration III.

Figure 6. - Comparison of combustion limits of several configurations with combustion limits of configurations I and II as shown in figure 5. Inlet conditions: temperature, 200° F; velocity, 220 feet per second. Fuel, isopentane with low-pressure injection.

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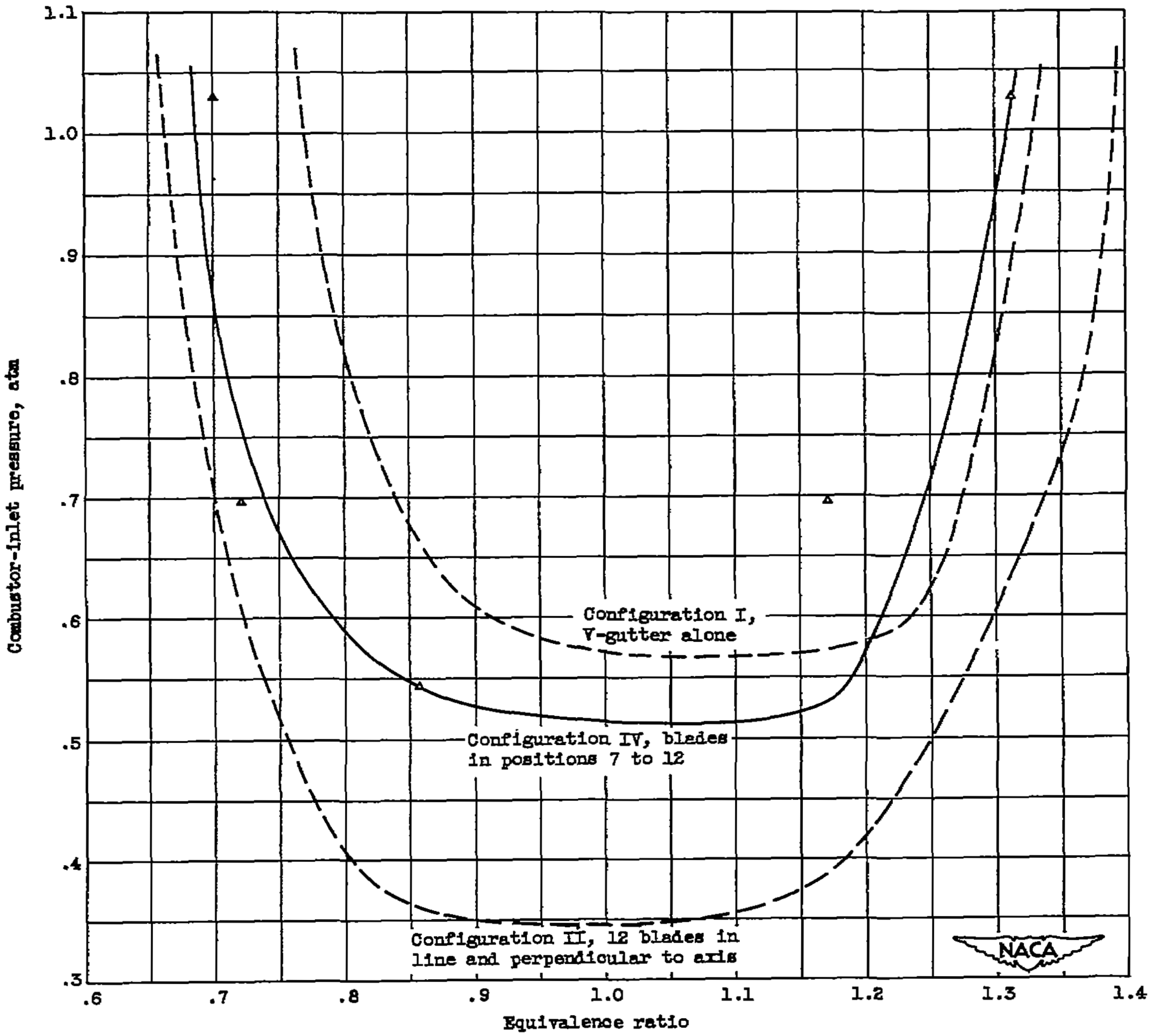


(b) Configuration IV.

Figure 6. - Continued. Comparison of combustion limits of several configurations with combustion limits of configurations I and II as shown in figure 5. Inlet conditions: temperature, 200° F; velocity, 220 feet per second. Fuel, isopentane with low-pressure injection.

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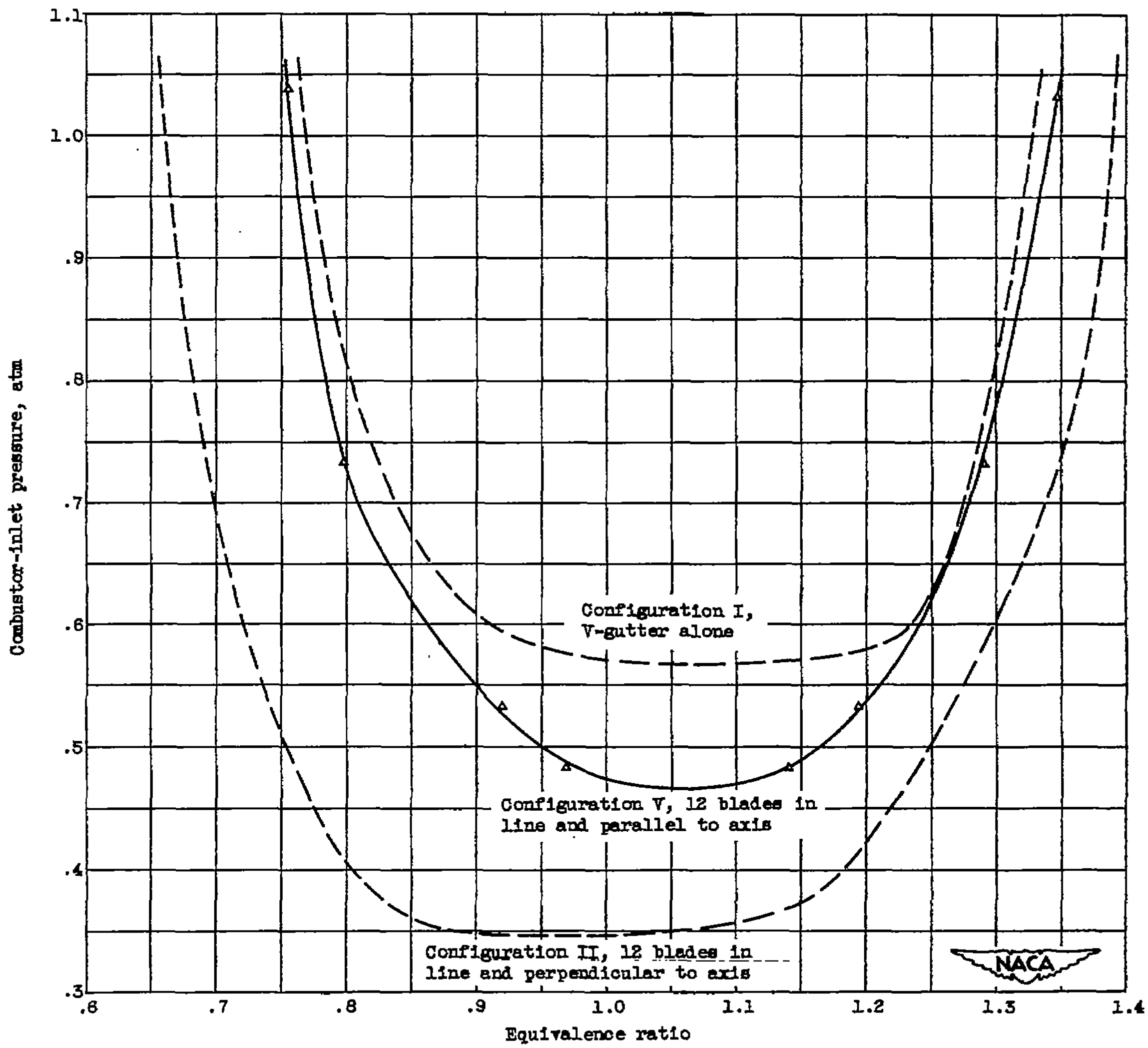


(c) Configuration V.

Figure 6. - Continued. Comparison of combustion limits of several configurations with combustion limits of configurations I and II as shown in figure 5. Inlet conditions: temperature, 200° F; velocity, 220 feet per second. Fuel, isopentane with low-pressure injection.

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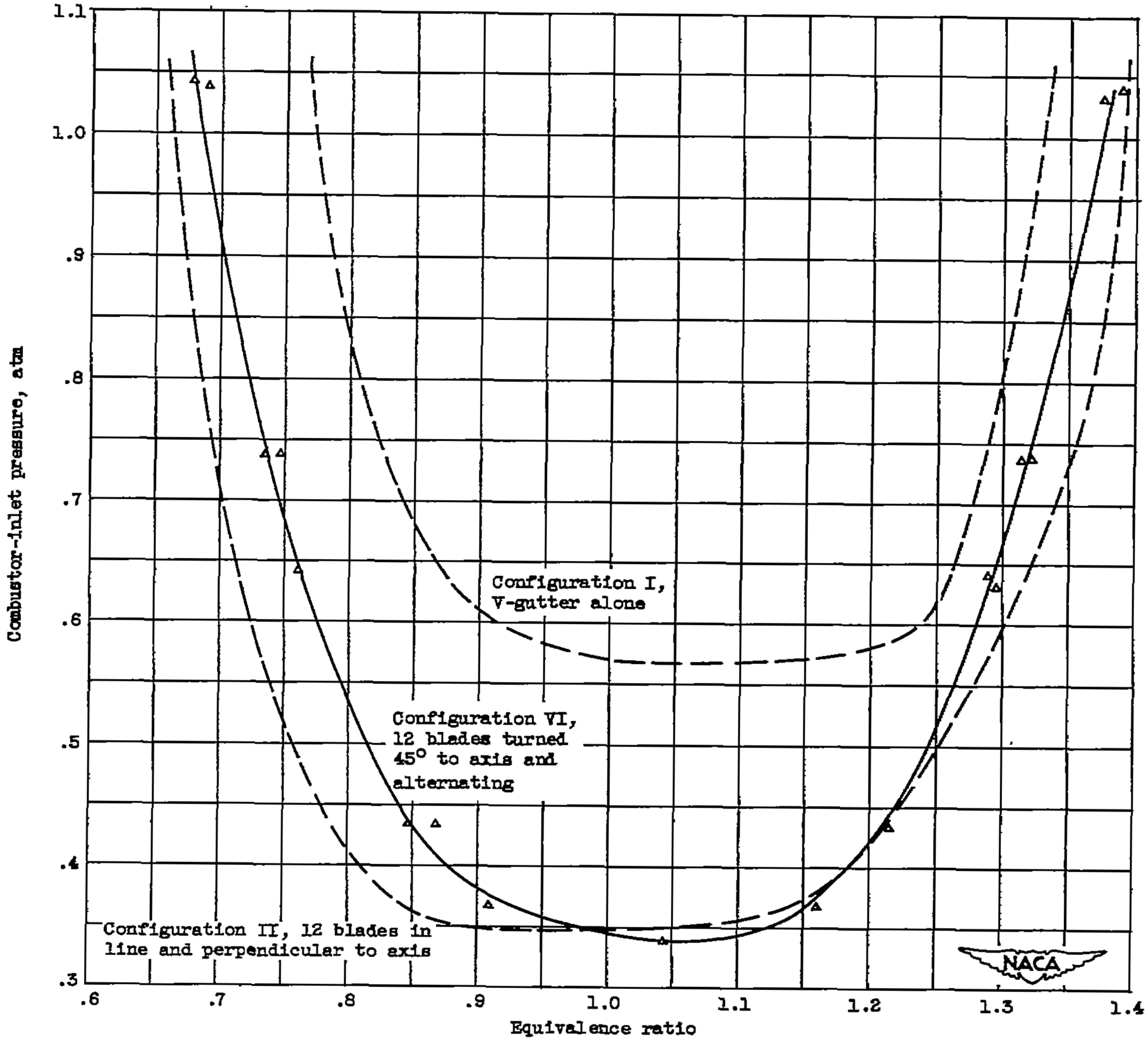


(d) Configuration VI.

Figure 6. - Concluded. Comparison of combustion limits of several configurations with combustion limits of configurations I and II as shown in figure 5. Inlet conditions: temperature, 200° F; velocity, 220 feet per second. Fuel, isopentane with low-pressure injection.

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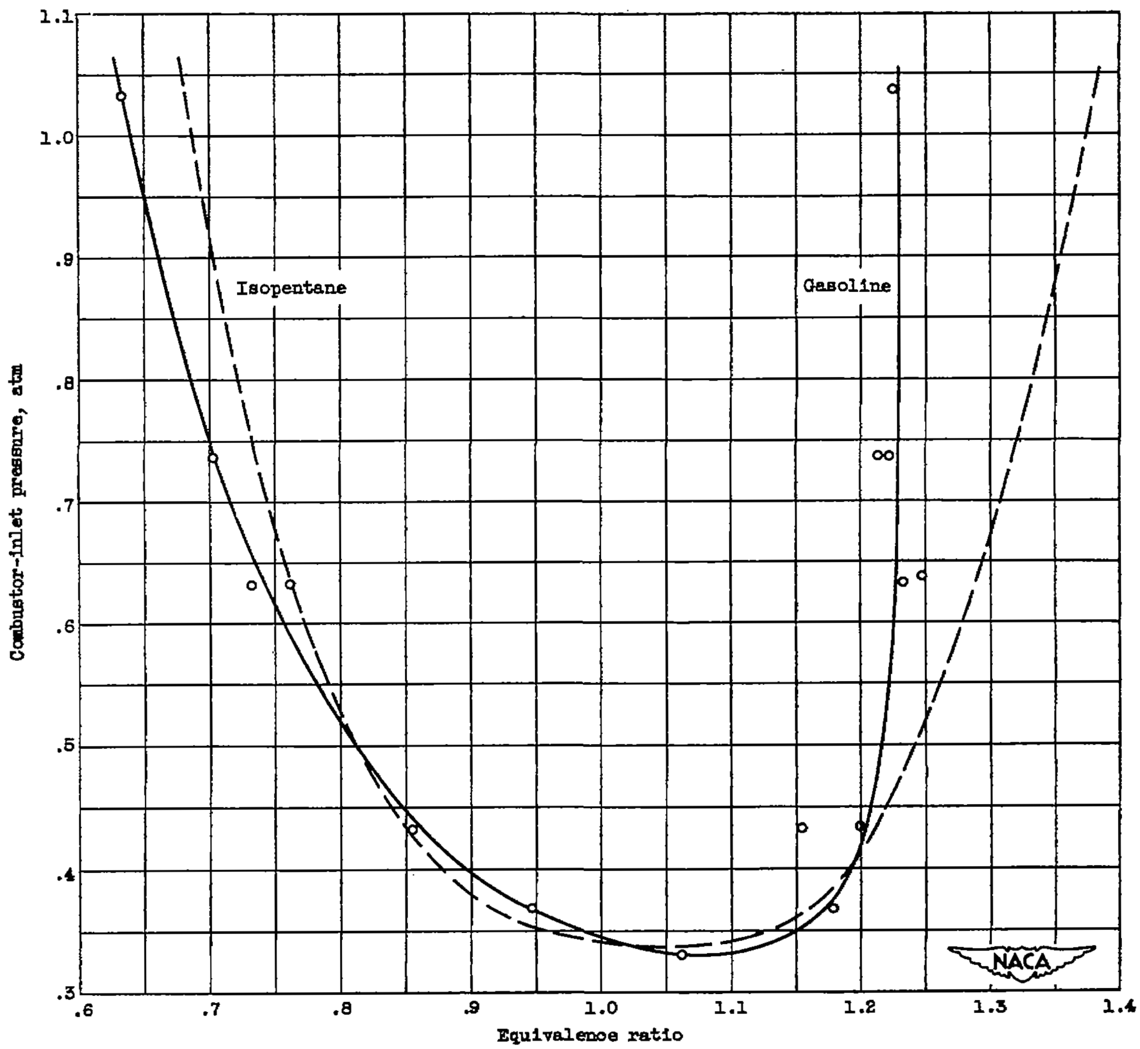


Figure 7. - Comparison of combustion limits of gasoline and isopentane in configuration VI. Inlet conditions: temperature, 160° F; velocity, 220 feet per second. Low-pressure fuel injection.

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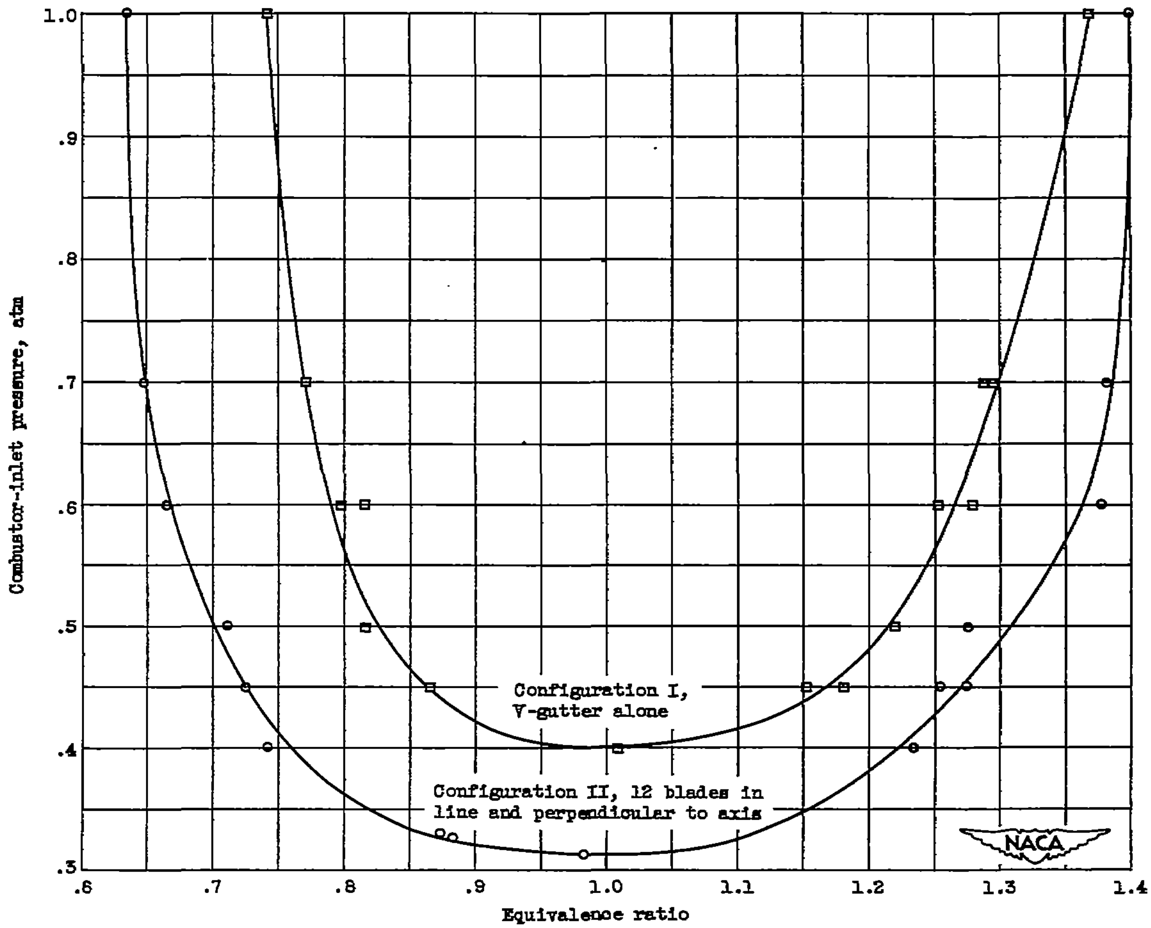


Figure 8. - Combustion limits of configurations I and II. Inlet conditions: temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

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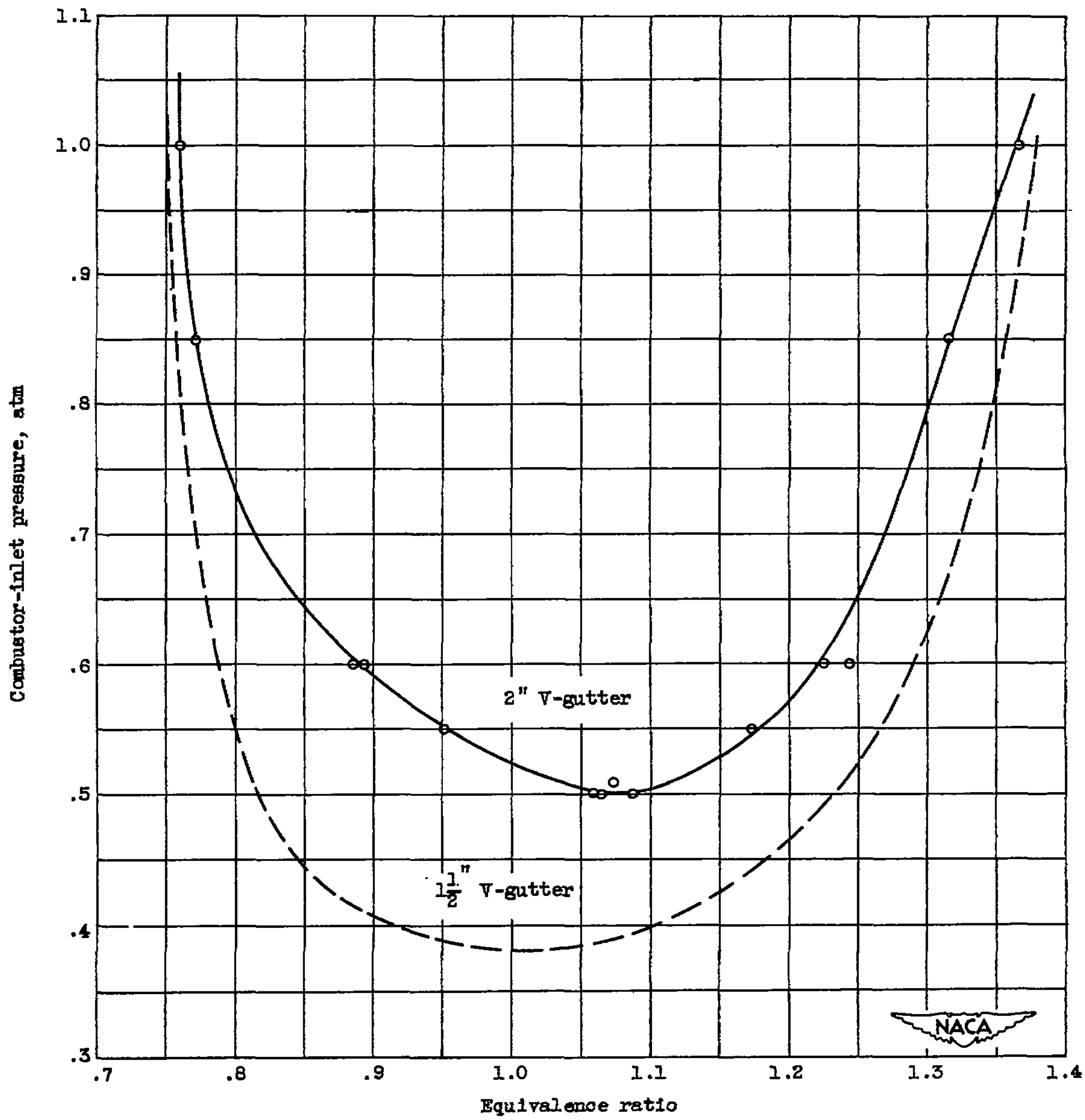


Figure 9. - Combustion limits of 2- and $1\frac{1}{2}$-inch V-gutters. Inlet conditions: temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

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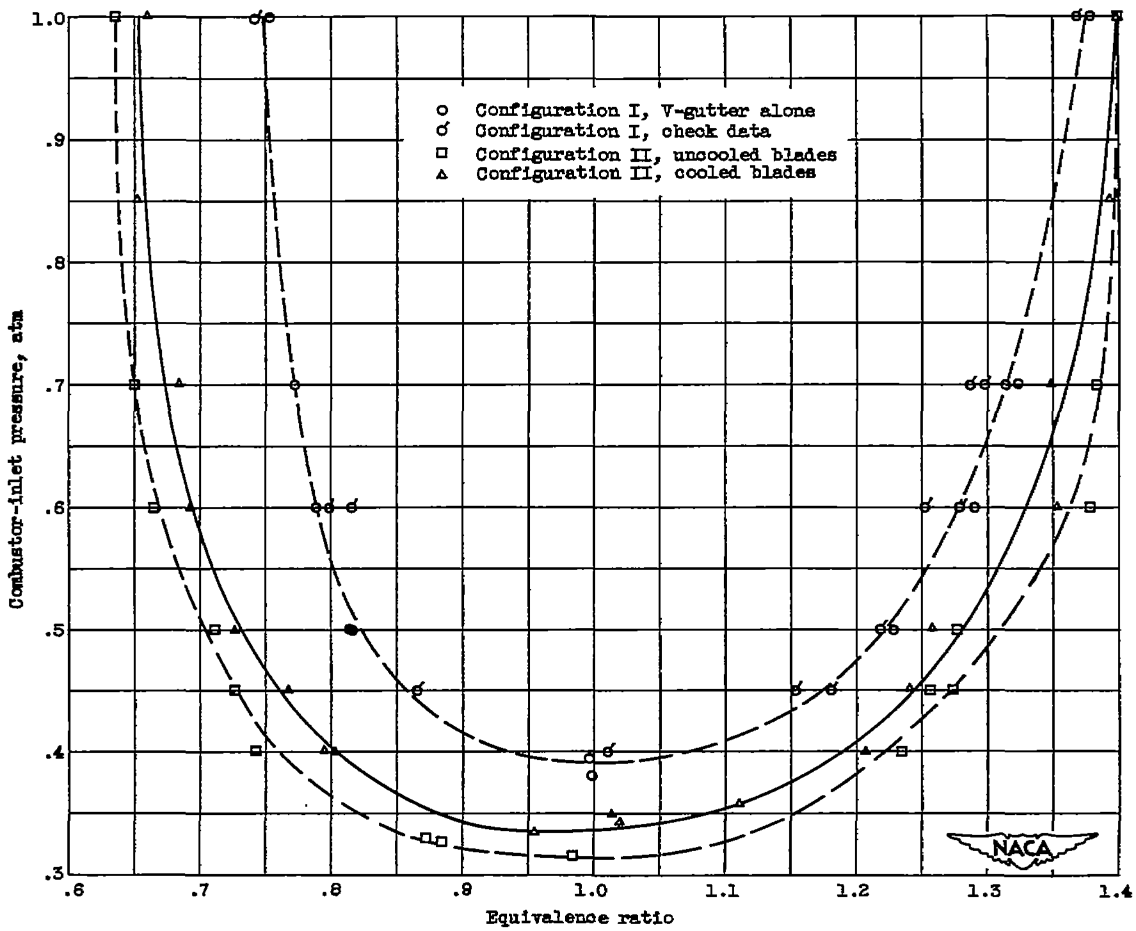


Figure 10. - Combustion limits of configuration I and of configuration II with both cooled and uncooled blades. Inlet conditions: temperature, 200° F; velocity, 230 feet per second. Fuel, gasoline with high-pressure injection.

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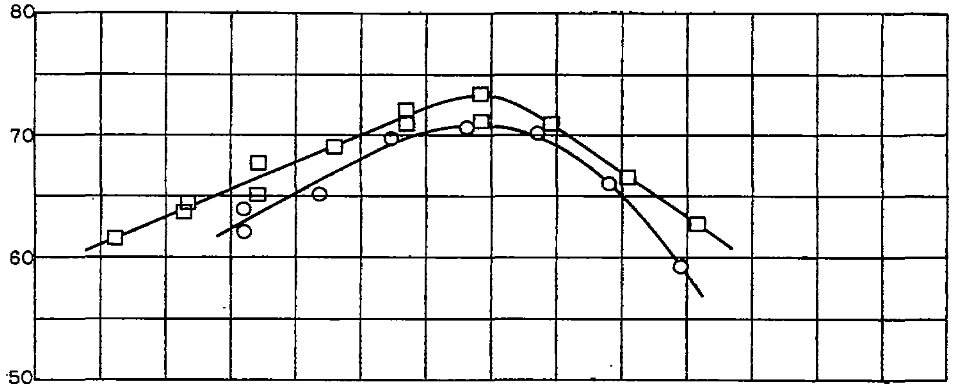
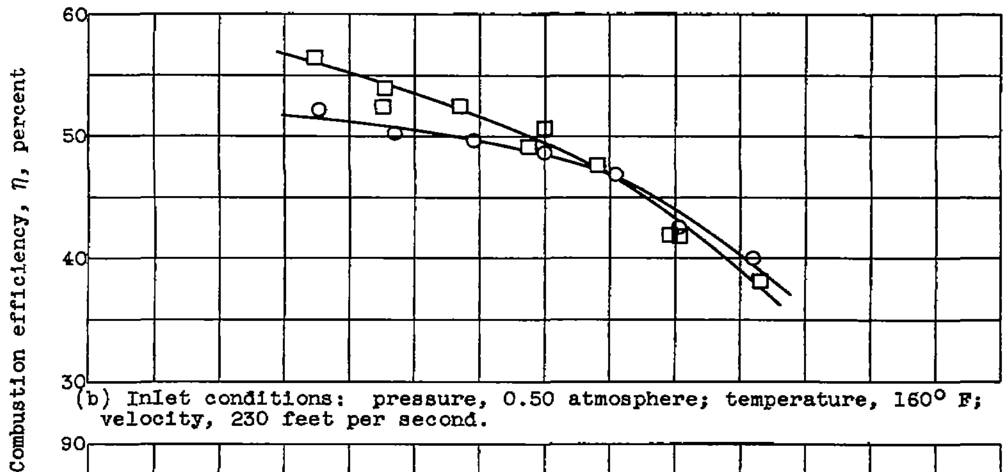
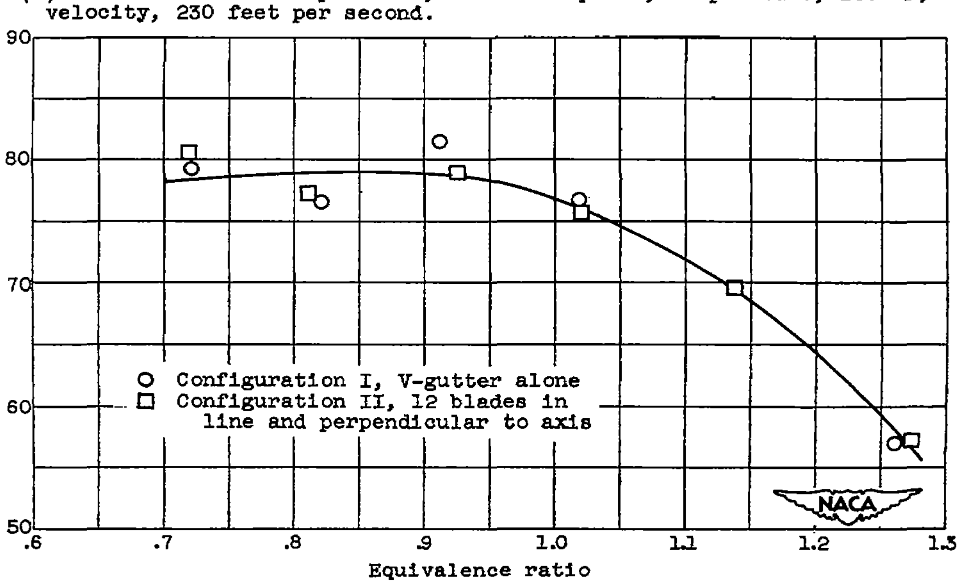



(a) Inlet conditions: pressure, 2.0 atmospheres; temperature, 220° F; velocity, 230 feet per second.




(b) Inlet conditions: pressure, 0.50 atmosphere; temperature, 160° F; velocity, 230 feet per second.




(c) Inlet conditions: pressure, 1.33 atmospheres; temperature, 260° F; velocity, 200 feet per second.

Figure 11. - Combustion efficiencies of configurations I and II at several inlet conditions. Fuel, isopentane with low-pressure injection.

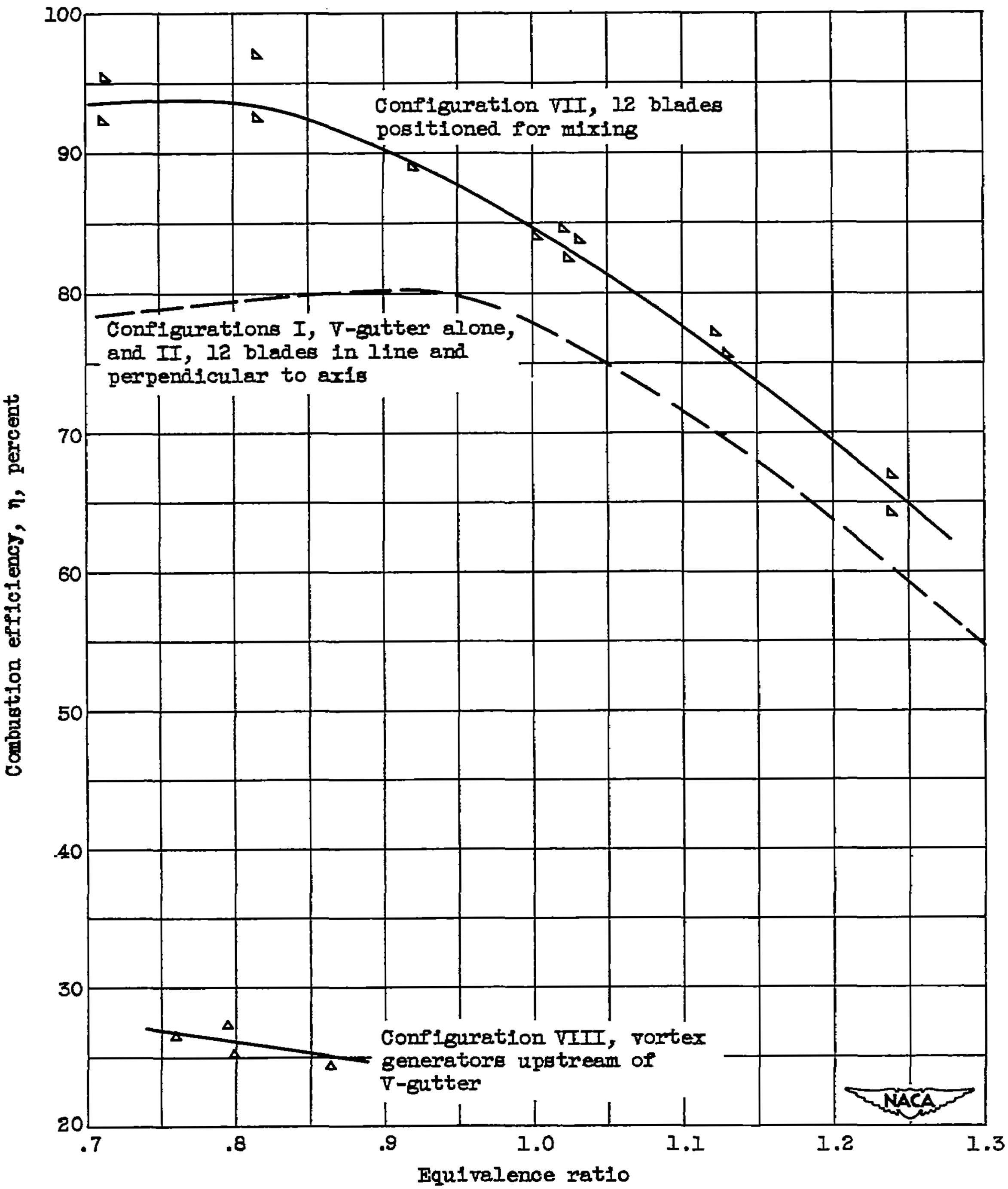



Figure 12. - Combustion efficiencies of configurations I, II, VII, and VIII. Inlet conditions: pressure, 1.33 atmospheres; temperature, 250° F; velocity, 200 feet per second. Fuel, isopentane with low-pressure injection.

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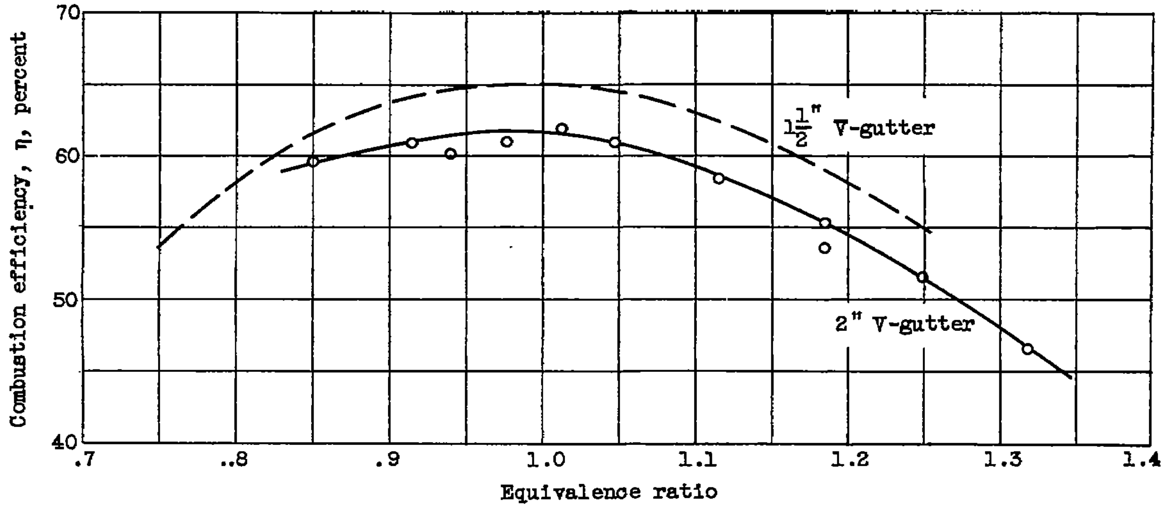


Figure 13. - Combustion efficiencies of $1\frac{1}{2}$- and 2-inch V-gutters. Inlet conditions: pressure, 1 atmosphere; temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

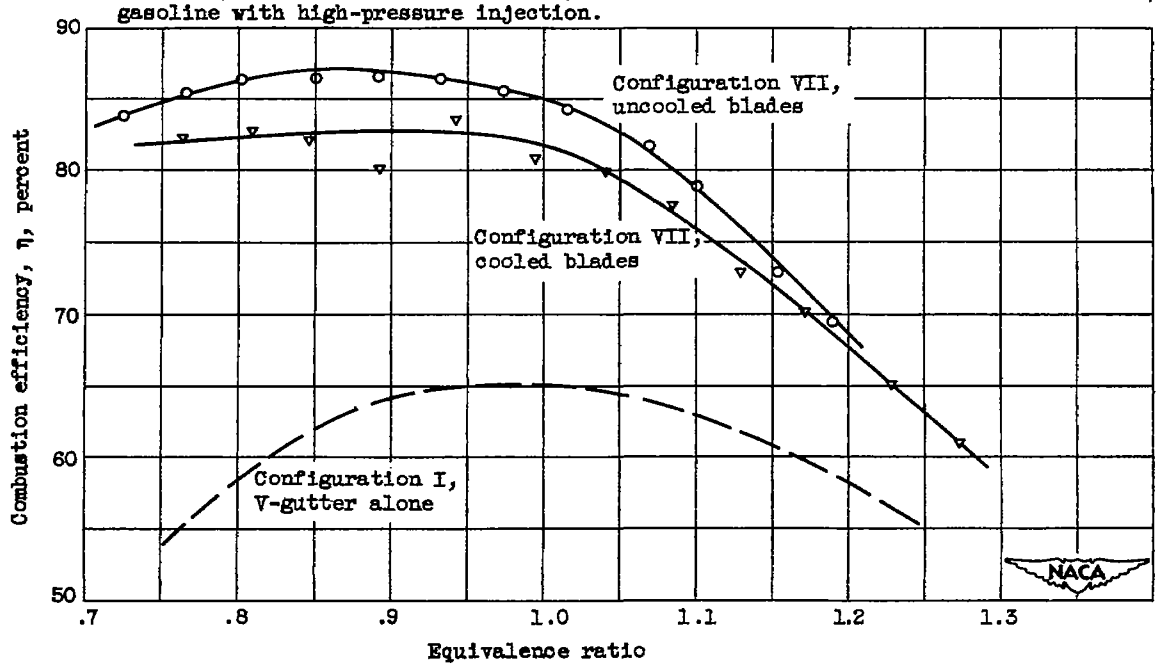


Figure 14. - Combustion efficiencies of configuration I and of configuration VII with both cooled and uncooled blades. Inlet conditions: pressure, 1 atmosphere; temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

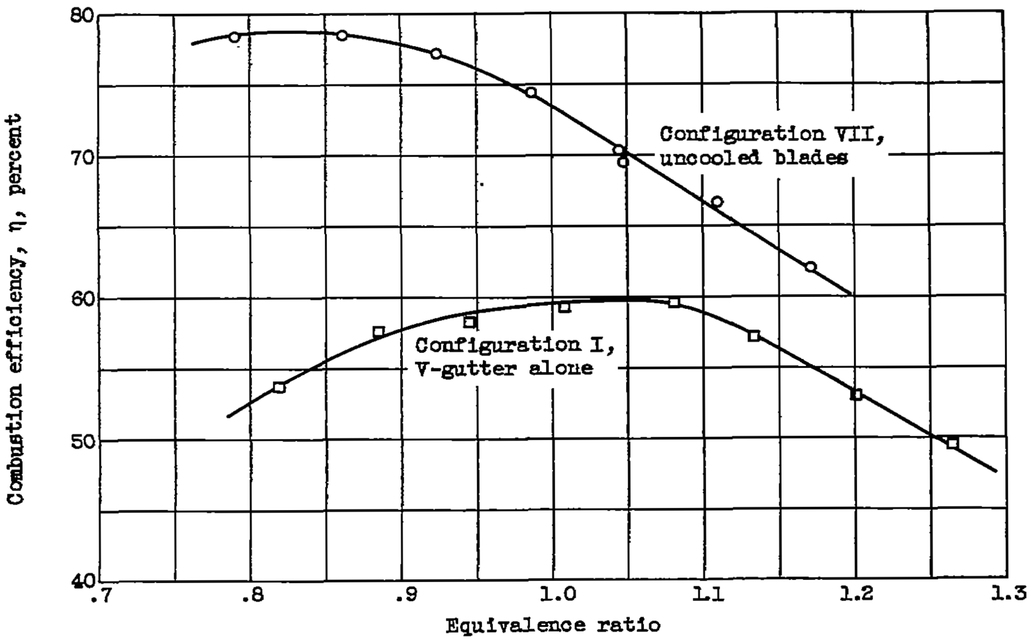


Figure 15. - Combustion efficiencies of configurations I and VII. Inlet conditions: pressure, 0.67 atmosphere; temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

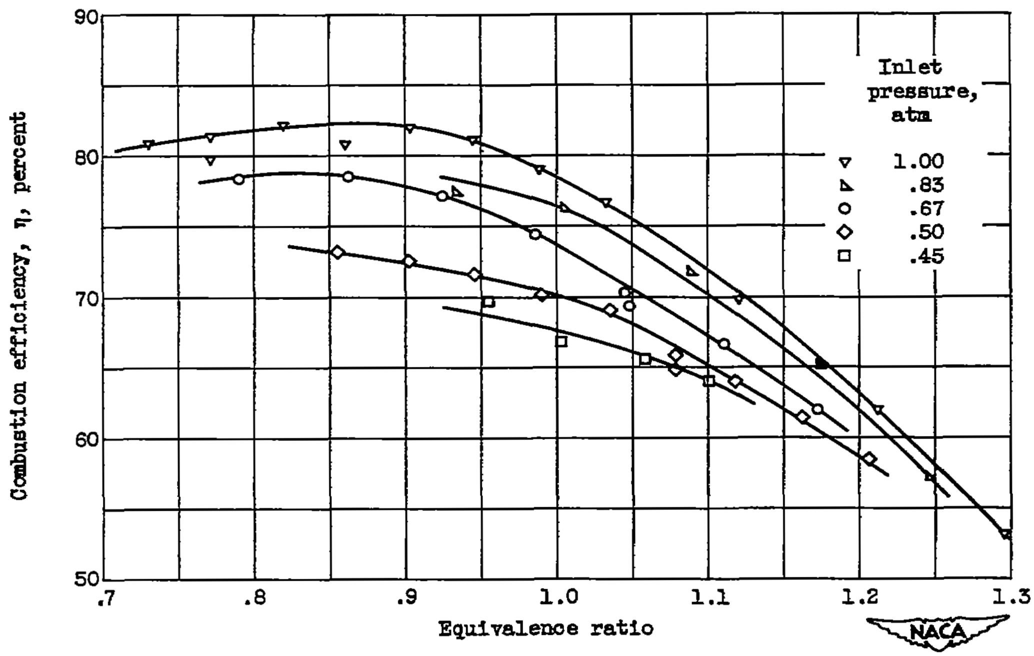


Figure 16. - Combustion efficiencies of configuration VII at several inlet pressures. Inlet conditions: temperature, 200° F; velocity, 200 feet per second. Fuel, gasoline with high-pressure injection.

[redacted]

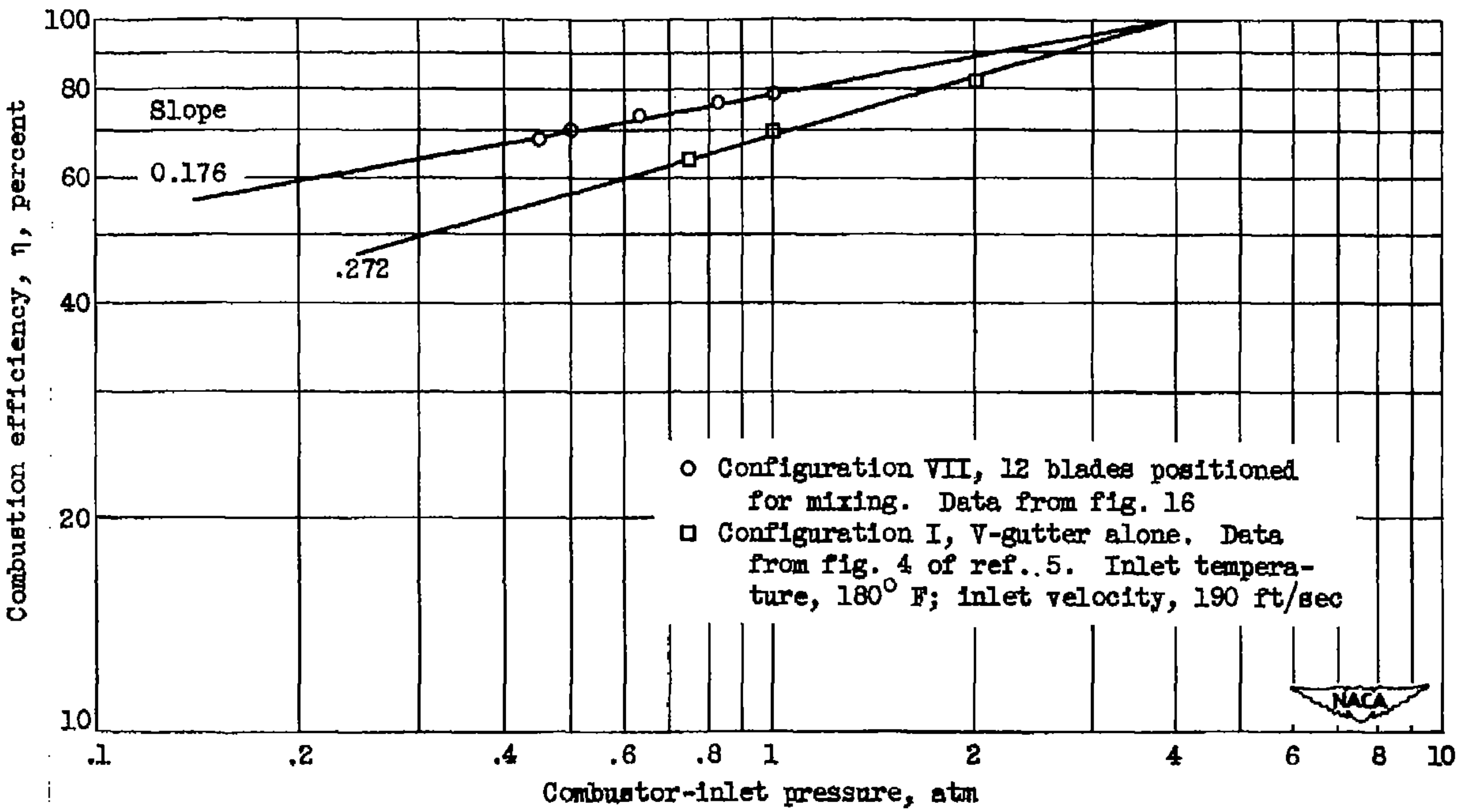


Figure 17. - Comparison of variation of combustion efficiency with inlet pressure of configurations I and VII.

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SECURITY INFORMATION

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